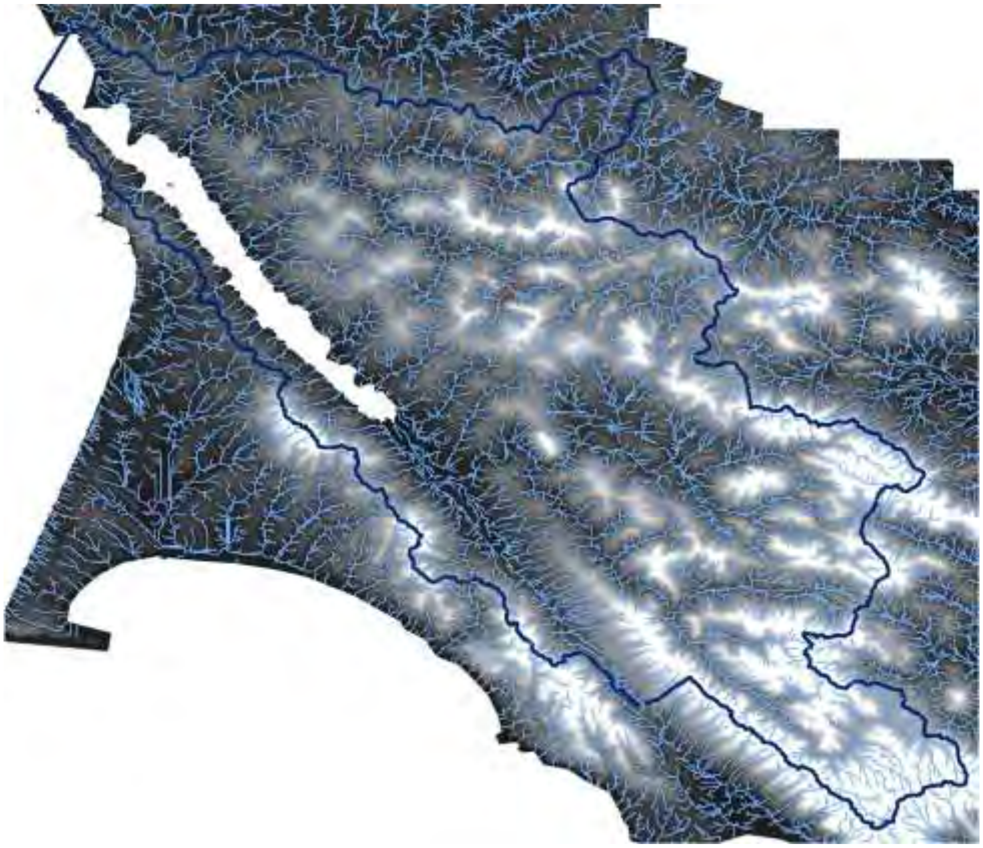
Tomales Bay Wetlands Restoration and Monitoring Program (2007-2012)

Final Water Quality Technical Report and Program Summary



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Cover: Geographic Information System (GIS) view of the watershed using LiDAR-derived elevation and streams. Tomales Bay watershed boundary shown in dark blue. Image created in ESRI ArcMap by Rob Carson, because of the extraordinary volunteer help from GIS guru Joel Grapentine.

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Executive Summary

The Tomales Bay Watershed Council Foundation (TBWCF) and Point Reyes National Seashore Association (PRNSA) are collaborating on this project to integrate the restoration of the Giacomini Wetland and water quality monitoring to reduce and eliminate existing threats, and to identify emerging threats that face this critically important watershed. By nesting a major restoration effort within a comprehensive monitoring program, this project employs an integrated strategy to both improve water quality and to assess the effectiveness of restoration efforts in improving water quality at the watershed scale. The information collected during this program will inform future restoration activities and priorities.

The project has three main water quality components: 1) The Trends Program which focuses on long-term monitoring at fixed sites throughout the watershed to monitor water quality trends; 2) the Source Area Program which focuses on identifying and characterizing existing water quality threats in target sub-watersheds selected annually; and 3) the Giacomini Wetlands Restoration Project which monitors the restoration project area and local reference areas before, during and after restoration to evaluate changes in water quality conditions. This report presents Trends Program and Source Area Program activities, particularly summary and analysis of water quality data collected from December 2007 through September 30, 2012. Data in this report is summarized by water year (i.e. October 1, 2011-September 30, 2012 is WY12). The summary and analysis of the Giacomini Wetland Restoration Project water quality data is provided in Appendix A of this document.

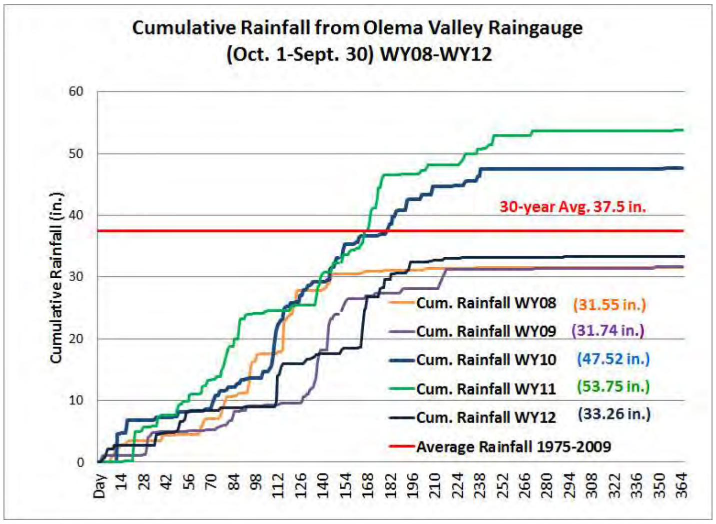
Monitoring Overview

Monitoring methods followed the approved protocol contained in the project Monitoring Plan (MP) and Quality Assurance Project Plan (QAPP) (Carson, 2007). Sampling includes collection of both field and lab measured water quality parameters. Core parameters measured in the field include temperature (air and water), dissolved oxygen, pH, specific conductance, salinity and discharge where available. Laboratory analyzed parameters include indicator bacteria (total and fecal coliform bacteria), nutrients (ammonia, nitrate, total Kjeldahl nitrogen (TKN), total phosphorus (TP)), and sediment (turbidity).

The data is presented by major sub-watershed (Lagunitas and Walker Creeks), or by groups of sites in the case of the Bay sites and the east- and west-shore coastal drainages.

The long-term Trends Program monitored 11 tributary sites, and four Bay sites (see map at right) during weekly wet-season site visits (approximately October or November through April or May), and twice-monthly site visits during the dry season (April or May through October or November). Tributary stations were visited between 28 and 41 times each year (fewer in the case of intermittent streams). Bay sites were sampled at least 24 times in WY08 covering both the wet and dry season. Starting during the WY09 season, Bay sites were not regularly sampled during the wet season due to logistical constraints of sampling partners. As a result, we cannot assess year-round water quality conditions in Bay waters using our program data.

The parameters of greatest concern for the Trends Program monitoring are those for which there are either Regional Water Quality Control Board (RWQCB) water quality objectives or Environmental Protection Agency (EPA) Clean Water Act impairment listings (303d list). The former include pH and dissolved oxygen (DO). The latter includes pathogens, nutrients and sediment for Lagunitas Creek, Walker Creek and Tomales Bay itself. Walker Creek and Tomales Bay are also both listed as impaired by mercury due to legacy cinnabar (mercury ore) mining in the Walker Creek watershed.



Results and Analysis

The five years of monitoring by this program encompassed very different hydrologic conditions, with a recorded range of cumulative precipitation from 31.55-inches to 53.75-inches. The 30-year average for this gauge is 37.5-inches (with a range of about 17-inches in 1977 to 82-inches in 1983).

Field Measurements

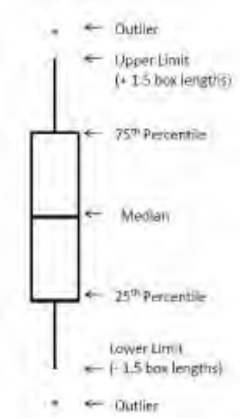
At tributary sites, samples met the RWQCB water quality objectives to support beneficial uses during most sampling visits. An analysis of the entire Trends Program dataset shows that measured dissolved oxygen (DO) met the RWQCB DO objective of 7.0 mg/L in 91.3% of all samples (WY08-WY12), and met the RWQCB pH objective (>6.5 and <8.5) in 97.2% of all samples (WY08-WY12).

Bacteria

The TBWC's water quality monitoring results suggest that the monitored tributaries are not complying with bacteria objectives proposed in the pathogen TMDL for Tomales Bay. For pathogens, the RWQCB set a contact recreation fecal coliform objective that the 90th percentile results not exceed 400 MPN/100mL, and a shellfish harvesting objective that the 90th percentile results not exceed 43 MPN/100mL (RWQCB 2001). Combined fecal coliform results from all tributary sites and all water years shows that almost 30% of samples exceeded 400 MPN/100mL. When considering combined WY08-WY12 data by each tributary site, no site had fewer than 10% of samples exceeding 400 MPN/100mL.

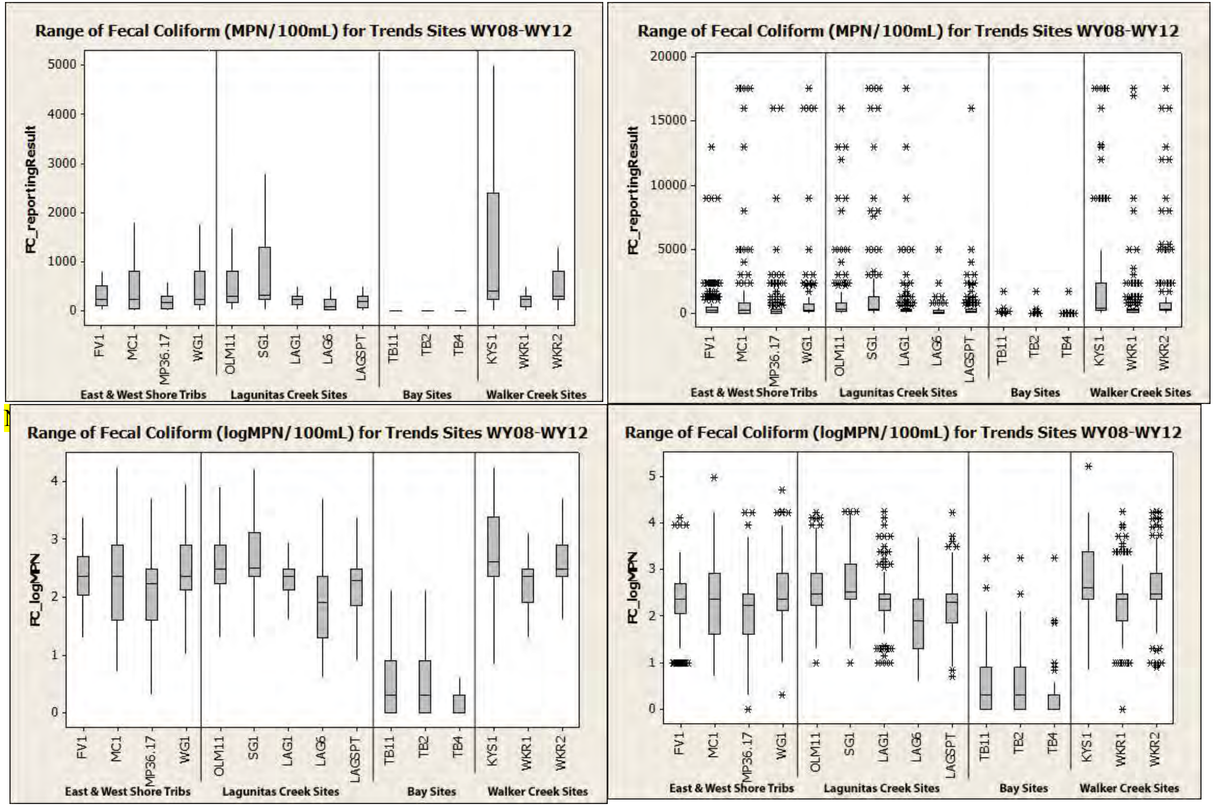
At outer-, mid-, and inner-Tomales Bay sites, where the shellfish harvesting objective is more appropriate, 8.9% of samples exceeded the single-sample objective for shellfish harvesting over WY08-WY12. However, sampling did not occur at Bay sites during wet-season, adverse weather events, or during Bay closure due to recent cumulative precipitation, when bacteria levels are most likely to be elevated. The consequence is that program data for the Bay sites is insufficient to capture the true range of annual water quality conditions, because it does not include what we suspect would be results at the upper end of the annual range.

Below are graphs (boxplots) of lab sample results by station through WY12. A boxplot displays information about the range and distribution of data within the range (see figure at right). For the graphs below, those on the left side do not include outlier results (those above or below the limits defined by the whisker length of 1.5-times the middle 50% range box). The graphs on the right include outlier results, shown by the asterisks (*) and so, these graphs show the true range of results (with exceptions noted below graphs).



The first set of graphs shows the range of fecal coliform bacteria results. The first side-by-side set of graphs below is the actual fecal coliform ‘most probable number’ or MPN per 100mL of sample water. The second side-by-side set shows the range of log values of the fecal coliform results which enables comparison of the wide-ranging values like bacteria results on a smaller scale with more resolution. For example, the relative difference among Bay sites, with the inner-Bay site (TB11) elevated compared to the outer- and mid-Bay sites, is only apparent on the graphs of the log values of the fecal coliform results. The results also show that elevated levels of bacteria are chronic for some tributaries, including Keys Creek (KYS1), San Geronimo Creek (SG1) and Millerton Gulch (MC1). Also evident, however, is that periodically most monitored tributaries had elevated, or extremely elevated bacteria results shown in the scatter of extreme outliers on the graphs at right.

Bacteria Results by Sub-Watershed and Site – All Water Years Combined



Nutrients

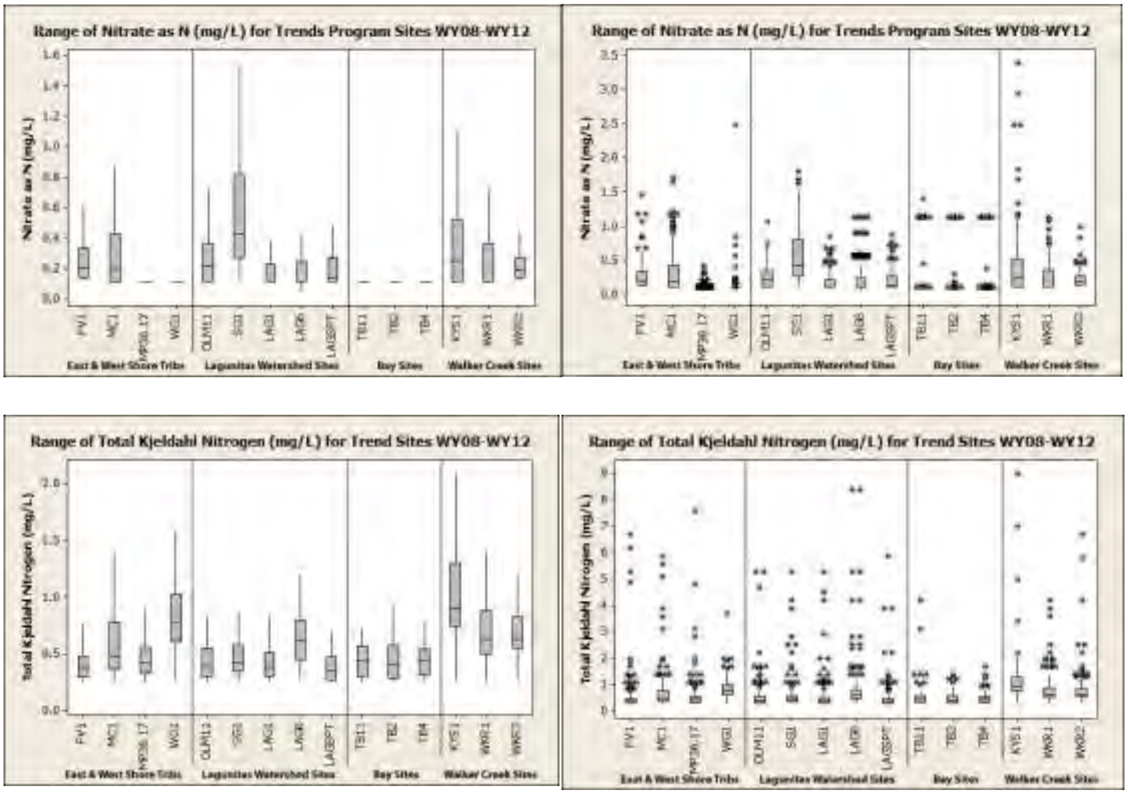
While there nutrient water quality objectives have not been established by the RWQCB for surface waters, observed nutrient levels in the watershed were relatively low. We detected forms of nitrogen in most samples from both tributary and Bay sites during WY08-WY12 (nitrate (NO_3) detections over 53% of samples; TKN detections over 90% of samples). Ammonia (NH_3) and total phosphorus (TP) detections were very low (ammonia about 3% of samples from WY08-WY10; and TP about 14% of samples from WY08-WY10). The very low levels of phosphorus detected in samples, and the ample available nitrogen suggests that phosphorus is the limiting nutrient in the watershed. Despite the importance of monitoring the limiting nutrient, we discontinued the analysis of samples for TP during WY10 and ammonia in WY11 because the number of detections for total phosphorus (TP) and ammonia at monitored locations was very low and our contract laboratory was unable to provide more sensitive analysis.

Nitrogen is an abundant nutrient in our watershed tributaries and in the Bay. The dynamics of the nitrogen cycle, and the relative abundance of each form, can provide additional information about the types of sources and impacts on the aquatic system. Major potential sources of nitrogen in the watershed include decomposing organic material, human and animal waste, and fertilizers. The Trends Program primarily monitors concentrations of nitrate (NO_3) and total Kjeldahl nitrogen (TKN). The former is the most stable, and most abundant, form of dissolved nitrogen, and the latter is the sum of organic nitrogen and ammonia. Sources of nitrates include animal (domestic, livestock and wildlife) waste, human waste from compromised septic systems or treatment system spills, as well as decomposed ammonia, nitrite and organic nitrogen. The main sources of organic nitrogen are decomposing organic material like vegetation (leaf litter, plants, roots, etc.), animals, etc. Organic nitrogen is often associated with soil particles, increasing with erosion and sediment-laden runoff. In general, ammonia is very short-lived (though potentially lethal) in aquatic systems, quickly undergoing chemical transformation to nitrite (NO_2), then to nitrate (NO_3). The consequence of this is that its detection usually suggests a proximate source such as livestock and wildlife.

Nitrate as nitrogen and TKN levels were elevated relative to the recommended EPA criteria for Total Nitrogen of 0.38 mg/L for ecoregion III rivers and streams (EPA 2000), but never exceeded the EPA drinking water standard of 10 mg/L nitrate-N (44 mg/L nitrate NO_3). Comparison of total Kjeldahl nitrogen (TKN), ammonia and nitrate results suggests that organic nitrogen is the largest available nutrient constituent in the watershed, and that spikes in most nutrient concentrations appear to be driven by storm-related runoff and hydrologic connection to upstream sources.

Again, the nutrient results show that elevated levels of nitrate are chronic in some tributaries, including Keys Creek (KYS1), San Geronimo Creek (SG1), Olema Creek (OLM11) and Millerton Gulch (MC1). The results of TKN analysis (the second side-by-side set of graphs) demonstrate that organic nitrogen is a major nutrient source in the tributaries, with the most elevated results occurring during storm runoff events. This is particularly evident from the sites in the Walker Creek watershed, and consistent with the association between organic nitrogen and sediment particles in the water column. Also of note is that San Geronimo Creek site does not demonstrate strongly elevated TKN relative to other Lagunitas Creek watershed sites, contrary to a comparison nitrate results in Lagunitas Creek sites. This suggests that while the nitrogen input in the San Geronimo Creek watershed includes organic nitrogen, it is at levels consistent with other Lagunitas watershed sites. It also suggests that there is a significant source of dissolved nitrate in the San Geronimo Creek watershed itself. Potential sources include the well-documented presence of compromised septic systems (TBWC 2007) and chemical fertilizer runoff from home gardens or the golf course.

Nutrient Results by Sub-Watershed and Site – All Water Years Combined



Note: Two extreme outlier results of 15 mg/L (WG1) and 39 mg/L (MC1) were omitted from TKN graphs.

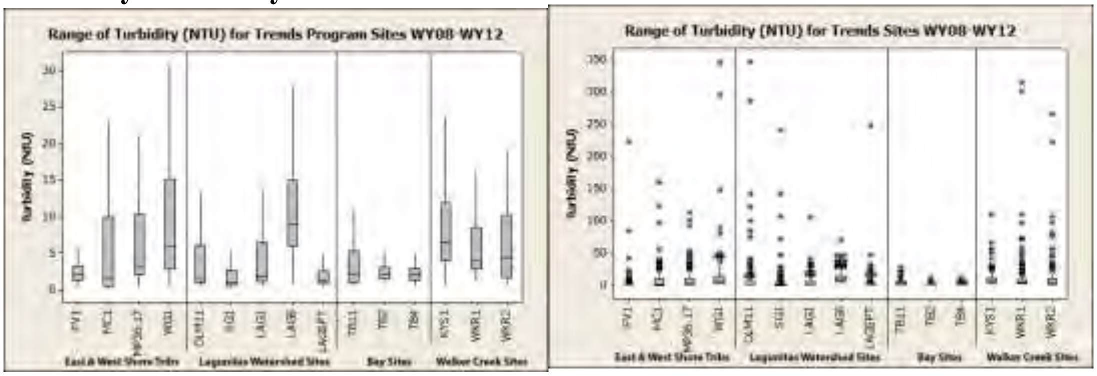
Sediment

There is no turbidity or other sediment water quality objectives set by the RWQCB, but the Basin Plan states that “waters shall be free of changes in turbidity that cause nuisance or adversely affect beneficial uses.” The EPA guidance provides recommended turbidity reference criteria for ecoregion III rivers and streams of 1.84 NTU and 1.9 NTU for subregion 6 rivers and streams (based on the 25th percentile year round) (EPA 2000). The mean turbidity for most monitored tributaries exceeded this recommended level in all water years.

The turbidity levels observed in the watershed are heavily driven by storms and runoff events at both tributary and Bay sites. Almost all elevated turbidity levels occurred during or after runoff events. Only at intermittent tributaries did we observe elevated turbidity during summer months as freshwater input slowed, and algal growth flourished Sites with elevated turbidity were present in each major watershed grouping, and almost all sites had periodic extreme values noted on the graph below at right. Of note are the consistently lower levels at First Valley Creek (FV1) on the west shore, and at upper Lagunitas Creek (LAGSPT). At the Bay sites, the inner-Bay site

(TB11) demonstrates a higher range of values reflecting the strong influence of Lagunitas Creek on water clarity in the inner Bay.

Turbidity Results by Sub-Watershed and Site – All Water Years Combined



Note: Two extreme outlier results of 899 NTU (LAG1) &1,000 NTU (WKR2) were omitted from Turbidity graph.

Source Area Program

Source Area Program sampling during WY10 focused on sampling multiple locations in selected subwatersheds (Keys Creek, Tomasini Creek, San Geronimo Creek, Third Valley Creek) to characterize the nature and geographic patterns of water quality on a finer scale. Source Area Program sampling was limited during WY11 and WY12 wet seasons with efforts focused on capturing storm profiles of pollutant concentrations in the San Geronimo Creek, Olema Creek, First Valley Creek and Millerton Gulch watersheds. The goal of this effort was to measure the severity and duration of elevated pollutant loads resulting from different storm events. To accomplish this, staff sampled on day 1 (rising limb), day 2 (peak or falling limb), day 3 (falling limb) and/or days 4 or 5 (return to base flow) of targeted storms. The close spacing of storms during WY11 and WY12 storms frustrated attempts to gather the latter (day 3-5) samples, however differences between monitored watersheds were observed. The Source Area Program data is presented in Appendix F to this document.

Outreach and Education

Outreach and education activities undertaken during the program included: presentations to the Council, various Technical Advisory Committees (TACs) and to Council partners; public outreach through electronic and printed newsletters, educational workshops with students and teachers, maintenance of our on-line water quality data resource, and providing a technical point of contact for watershed water quality information.

Conclusions and Next Steps

Initial analysis of gathered data compared with rainfall data suggests that there are not discernible downward trends in pollutant concentrations across the watershed over the five years of program monitoring. Storm-related runoff appears to be the primary driver of adverse water quality conditions including bacteria, nutrients and sediment levels. The program has maintained consistent monitoring during five wet-seasons, capturing significant climatic variability which should allow for a more robust analysis of both legacy data and future TBWC program data. Continuation of this program is critical to the effort to determine long-term water quality trends in the watershed, and the Tomales Bay Watershed Council water quality monitoring program will continue monitoring at Trends program sites into the future as funding allows. Funding for each program element, including the Trends, Source Area and Giacomini Wetland Restoration Project monitoring after September 2012 will depend on the available resources of the organizations involved in monitoring.

Introduction

Watershed Description

Located in western Marin County, California, approximately 40 miles northwest of San Francisco, the Tomales Bay Watershed encompasses almost 220-square miles bounded by the slopes of Mt. Tamalpais to the south, the Inverness Ridge to the west and the agricultural lands to the east. Tomales Bay itself is an approximately 12 miles long flooded valley, covering 10.8 square-miles, straddling the San Andreas Fault. The Bay is less than a mile wide, and has an average depth of less than 20 feet (RWQCB 2007).

Figure 1 – Major Watersheds of Tomales Bay

Most of the freshwater delivered to the Bay originates in two major sub watersheds, Lagunitas Creek and Walker Creek. The Lagunitas Creek watershed, which includes San Geronimo Creek, is the largest sub-watershed to Tomales Bay and, together with the Olema Creek watershed, delivers nearly two-thirds of the freshwater input to the Bay, despite representing only 52% of the watershed area (Fischer, et al 1996). The second-largest drainage is the Walker Creek watershed to the northeast of the Bay. The Walker Creek watershed, which includes the Keys, Chileno, Sausal, Salmon and Arroyo Creek drainages, makes up about 35% of the Tomales Bay watershed area, but produces only about 25% of the freshwater delivery to the Bay (Fischer, et al. 1996). The approximately 10% of remaining freshwater input is delivered by the small drainages that line the east and west shores of the Bay and represent about 13% of the watershed area.

The following section offers a description of the major sub-watersheds of the Tomales Bay watershed, as well as locations of Trends Program sampling sites.

Figure 2 – Subwatersheds in the Tomales Bay Watershed

Lagunitas Creek Watershed

The Lagunitas Creek watershed covers an area of 83.1 square miles and includes the monitored subwatershed of San Geronimo Creek watershed that covers an area of approximately 9.37 square miles. Another significant tributary of Lagunitas Creek is the Olema Creek watershed which covers an area of 14.7 square miles. The Trends program has established four fixed-site monitoring stations at the following locations: the most upstream site is on San Geronimo Creek (SG1) at the MMWD stream gauge on Lagunitas Rd.; the next downstream site is on Lagunitas Creek at Samuel P. Taylor State Park (LAGSPT) at the USGS stream gauge (USGS 11460400); one site on Olema Creek below the Bear Valley Road bridge at the NPS stream gauge; and the most downstream site, Lagunitas Creek at green bridge just south of Point Reyes Station (LAG1). There is an additional site further downstream (LAG6) at the Lagunitas/Tomales Bay interface in the Giacomini wetlands. The LAG6 site is included below in the Tomales Bay site grouping, and includes the input from Olema Creek, the storm water system of Point Reyes Station, and small coastal drainages. Land-use in this watershed is a mix of agriculture, livestock grazing, dairy farming, low-density residential and park lands. Most residents in the watershed are served by onsite sewage disposal systems, with the exception of four small sewage treatment systems (RWQCB 2001). The Lagunitas Creek watershed provides 75% of the drinking water for residents in eastern Marin

County by way of five water catchment reservoirs operated by Marin Municipal Water District (MMWD). Four are in the upper Lagunitas watershed (Lake Lagunitas, Bon Tempe Lake, Alpine Lake and Kent Lake), and the fifth is the Nicasio Reservoir which spills to Lagunitas Creek about 2 miles south of Point Reyes Station.

East and West-Shore Coastal Tributaries

Coastal tributaries (those emptying directly into Tomales Bay) are numerous, though they contribute only about 10% of the freshwater input to the Bay (Fischer et al 1996). The Trends program has established four fixed-site monitoring stations in coastal drainages, two on the west shore, and two on the east. First Valley Creek (FV1) which drains an area of 0.80 square miles and is representative of the small coastal drainages along the west shore of the Bay with perennial flow originating from springs and fog-drip from the Inverness Ridge. The land-use in the drainage includes mostly residential (a significant number of which are only seasonally-used), and state and federal lands. White Gulch (WG1) which flows from the west, through the Tomales Point Tule elk reserve, encompasses an area of 0.34 square miles on the east side of Tomales Point and drains to the cove near Hog Island. Millerton Gulch (MC1) which drains an area of 3.7 square miles on the east shore just south of Millerton Point. The land-use in the Millerton Gulch drainage includes livestock grazing, a septage waste pond, and California State Park lands. During WY08, samples from Millerton Gulch were collected at the highway 1 bridge (MC1a), which is under significant tidal influence. The sampling site was moved upstream to the current sampling location at the southeastern end of state park lands to minimize these effects. Because of significant differences in field parameter values between the sites, the results are not combined in the analysis for WY08. The fourth coastal drainage is a small east shore tributary just south of the Marconi Conference Center (MP36.17) which drains an area of 0.4 square miles with minimal current human activity. The WG1 and MP36.17 sites are included as reference tributaries due to their relatively minimal development and impact from current human activities.

Walker Creek Watershed

The Walker Creek watershed covers an area of 75.5 square miles, which includes the monitored sub watershed of Keys Creek with an area of 9.37 square miles. The Trends program has established three fixed-site monitoring stations at the following locations: Walker Creek upstream site at Walker Creek Ranch (WKR2), approximately 1/4-mile upstream of the USGS streamgauge (USGS 11460750); Keys Creek at shoreline highway (KYS1); and Walker Creek downstream site at shoreline highway, just upstream of the Keys Creek confluence (WKR1). Land-use in this watershed is dominated by agriculture, livestock grazing and dairy farming, with some low-density residential. All households are served by onsite sewage disposal systems except the town of Tomales, which is served by a centralized wastewater treatment plant. There is one drinking water reservoir (Soulajule) in the Walker Creek watershed operated by MMWD.

Tomales Bay

The Trends program also monitors Bay water at four fixed-site stations along the length of Tomales Bay. The three northern sites were selected because they are located on shellfish leases and have been monitored for bacteria by the California Department of Public Health (CDPH). The outermost site (TB2) is located just outside the mouth of

Walker Creek, The mid-Bay site (TB4) is in the Bay about a mile north of the Marshall-Petaluma Road intersection with shoreline highway. The inner-Bay site is adjacent to Millerton Point, just north of the mouth of Millerton Gulch. The outer-, mid-, and inner-Bay sites are sampled by the oyster growers in conjunction with their regular sampling for the CDPH. The fourth Bay site (LAG6) is in the wetland interface between the Bay and Lagunitas Creek just north of the old north levee, and downstream of the Giacomini Wetland Restoration Project area. This innermost site has been monitored by the National Park Service since 2006, before, during and after the wetland restoration.

Background

The first goal identified in the TBWC Watershed Stewardship Plan (TBWC 2003) adopted in 2004 was to "Ensure water quality in Tomales Bay and tributary streams is sufficient to support natural resources and sustain beneficial uses." This goal is central to the past and current activities and interests of the TBWC and its members.

In order to best identify future restoration needs, trends in water quality, and sources of nonpoint water pollution, TBWC is currently assessing surface water quality throughout the watershed through this program. TBWC also provides a clearinghouse for regional water quality data, collected by member and outside agencies and groups leading to compilation and analysis of all available data to provide the "big picture" that is necessary to inform our resource management decisions and priorities (TBWC 2007).

A number of federally and state endangered [FE] [SE] and threatened [FT] [ST] species have historically or recently been documented in the watershed. Freshwater systems within the watershed support a variety of protected species including the California freshwater shrimp (*Syncharis pacifica)* [FE], coho salmon *(Oncorhynchus kisutch)*[FE/SE], steelhead trout (Oncorhynchus mykiss) [FT], and the California red-legged frog *(Rana aurora draytonii)* [FT]. Saltwater, or brackish systems in the watershed support the tidewater goby *(Eucyclogobius newberryi)* [FE]. Avian species occurring in the watershed that are listed as threatened or endangered include the California clapper rail *(Rallus longirostris obsoletus)* [FE; SE], Least Bell's vireo *(Vireo bellii pusillus)* [FE, SE], American peregrine falcon *(Falco peregrines anatum)* [SE], California black rail *(Laterallus jamaicensis coturniculus)* [ST], bank swallow *(Riparia riparia)* [ST], and sandhill crane *(Grus Canadensis tabida)* [ST]. (NPS 2007)

In addition to the occurrence of threatened or endangered species in the watershed, several water resources are listed by the Regional Water Quality Control Board (RWQCB) as impaired under Section 303(d) of the Clean Water Act. These listings imply that the listed water resources consistently fail to meet water quality standards set to ensure continuation of beneficial uses in these waters.

Beneficial uses of water bodies in the Tomales Bay watershed include contact and non-contact recreation, fish spawning and migration, cold freshwater habitat, and wildlife habitat. Water quality also has a direct impact on several other resources including water quality, mariculture, federal and state protected stream species and fish assemblages, amphibians and reptiles, riparian habitat, wetlands and aquatic macroinvertebrates.

The impairment listings under Section 303(d) in the watershed include: Tomales Bay, listed as impaired by pathogens, nutrients, sediment and mercury; Lagunitas Creek (including the Olema Creek watershed), listed as impaired by pathogens, nutrients and sediment; and Walker Creek, listed as impaired by pathogens, nutrients, sediment and mercury. There is currently a Total Maximum Daily Load (TMDL) in place for the watershed for pathogen contamination.

The occurrence of special status species, the listing of encompassed watersheds as impaired in Section 303(d) of the Clean Water Act, and the numerous projects to improve management practices on ranches and public lands underlines the importance of collecting and analyzing water quality data from the watershed as a whole to allow the evaluation of long-term water quality trends, and the positive or negative impacts of our activities in the watershed.

Program Overview

Funding Program: Initial funding for this project was provided through the SWRCB Prop. 50 Coastal Nonpoint Source Pollution Control Program (Grant Agreement number 06-344-552-0) through December 17, 2008. Funding for the project was restored through the SWRCB State Revolving Fund (SRF) Project No. C-06-6926-110, Agreement No. 08-304-550-0 starting on December 18, 2008. This grant funding for the program ended at the end of September 2012 with the end of the fifth water-year of monitoring.

Program Description: The Tomales Bay Watershed Council Foundation (TBWCF) and Point Reyes National Seashore Association (PRNSA) are collaborating on this project to integrate the restoration of the Giacomini Wetland and water quality monitoring to reduce and eliminate existing threats, and to identify emerging threats that face this critically important watershed. Tomales Bay and its watershed is a precious Pacific coast ecosystem at risk from existing and emerging threats. By nesting a major restoration effort within a comprehensive monitoring program, this project employs an integrated strategy to both improve water quality and to assess the effectiveness of restoration efforts in improving water quality at the watershed scale. The information collected during this program will inform future restoration activities and priorities.

Program goal: This integrated restoration and monitoring program seeks to determine long-term trends and to characterize and reduce threats to water quality and critical habitats in the Tomales Bay Watershed, as well as to assess the impacts of the Giacomini Wetlands Restoration Project (GWRP) on water quality. Based on the information gathered through this monitoring program, the Council will work to identify water quality problems, to develop solutions to these problems, and to provide support to realize these solutions by working with partners and landowners in the watershed to improve and protect water quality.

It is the desire of the Council to provide needed water quality information that will assist individuals, organizations and agencies that are responsible for and/or advocating for water quality protection and improvement within the Tomales Bay watershed. The information collected through this program will ultimately be used to increase our collective understanding about the benefits of specific efforts to improve water quality, and our ability to effectively and adaptively manage human impacts on water quality. All water quality data funded by this grant is public and will be disseminated through reports to the funders and to the public, and by request. Private property rights will be recognized, statutory responsibilities will be maintained, and voluntary cooperation will be encouraged and protected with data sensitivity considerations.

A complete program description, and more detailed information about methods can be found in the project Monitoring Plan and Quality-Assurance Project Plan (Carson, 2007). These documents and other program reports are available on our website at: http://www.tomalesbaywatershed.org/waterquality.html.

Program Objectives

The Monitoring Plan provides direction for a water quality monitoring program with an initial 3-year timeframe. Restoration of funding and changes to funding contracts allowed the continuation of this program, through the end of WY12 in September 2012. It is envisioned, however, that monitoring of long-term water quality trends in the watershed by the Tomales Bay Watershed Council will continue indefinitely, if funding allows.

Water Quality Monitoring Project (WQMP) Objectives:

- Provide the watershed community with the required data and analysis to determine improving, constant, or declining trends in Bay and tributary water quality;
- Form and maintain a clearinghouse of water quality data and monitoring activities that facilitates effective and efficient use of limited resources;
- Serve as source of information that will inform and promote actions to improve water quality; and
- Provide an understanding of source areas and categories for constituents of concern both in the Bay and on a sub-watershed and/or tributary scale.

Giacomini Wetland Restoration Project (GWRP) Water Quality Monitoring Objectives:

These objectives address the water quality monitoring of the GWRP. For a complete assessment of all long-term monitoring objectives of the GWRP, see complete project literature, including Parsons (2005).

- Provide strategic water quality monitoring before, during, and after a phased restoration effort to determine the short- and long-term effects of restoration on water quality within the Project Area and on the amount of contaminants delivered to Tomales Bay.
- Compare water quality conditions in the Project Area before, during, and after restoration to those of natural undiked tidal marshes in the Tomales Bay and adjacent watersheds to determine the degree of divergence prior to restoration and how well over time conditions in the restored Project Area move toward those of natural marshes after restoration.

Questions to be addressed by this monitoring program:

A. **Questions to be addressed by the TBWC monitoring program:**

- What are the natural ranges and the storm, seasonal and annual variability in water quality parameters in the Bay and its tributaries?
- At what locations do parameters fall outside the natural range and to what duration and extent?
- What are the pollutant loadings from controllable and uncontrollable sources and in the watershed, and how do the Bay and tributaries relate in this regard?
- What are the trends in the levels, fate and transport of pollutants in the watershed and the Bay, and how do the Bay and tributaries relate in these regards?
- How effective are actions to reduce pollutant loads?

B. **Questions to be addressed by GWRP water quality monitoring:**

- What is the response to restoration activities with respect to nutrients, pathogen indicators and carbon/productivity indicators?
- Over time, do conditions within the restored Project Area improve relative to pre-restoration conditions, and do they begin to move closer toward those in natural undiked tidal marshes in the Tomales Bay and adjacent watersheds?
- Does restoration of the Giacomini wetlands appear to have an effect on the quality of water delivered downstream to undiked natural marshes and Tomales Bay?

Program Summary

Project Milestones

Important milestones for this project:
May 2007 – Prop. 50 Grant Contract finalized with the TBWCF
September, 2007 – Contractor was hired by TBWC to prepare program documentation, and implement monitoring.
October 2007 – Completed and received approval from SWRB for project documentation, including project Monitoring Plan (Carson, 2007), and project Quality Assurance Project Plan (Carson, 2007)
November, 2007 – Received approval to begin sampling
December, 2007 – Began monitoring for long-term Trends Program, and two source-area sub-watersheds.
October, 2008 – Final levee breach on the Giacomini Wetland Restoration
December 2008 – Project funding was suspended during the state fiscal crisis. Sampling at long-term Trends sites continued during the funding suspension.
June 2009 – Project funding was restored through the SWRCB State Revolving Fund (SRF).
Funding restoration was retroactive to December 18, 2008.

Long-Term Trend Monitoring

Trend monitoring will generate water quality data of sufficient duration and representation to assess long-term shifts in water quality within Tomales Bay and its tributaries. There are numerous stakeholder efforts to manage sources of pollution for which feedback is needed to assess impacts and the effectiveness of restoration efforts. There are also regulatory and statutory needs for long-term trend water quality monitoring. This component of the monitoring program will give the watershed community the needed benchmarks to determine the success of management efforts and efficacy of regulatory policies. The duration of monitoring necessary to determine long-term trends in water quality will exceed this project funding, but will be continued as possible through the efforts of the TBWC and its' funding partners.

Parameters

The water quality parameters collected as part of the long-term Trends monitoring include core field parameters: temperature, conductivity/salinity, dissolved oxygen (DO) and pH; and lab parameters related to the 303d-list Clean Water Act impairments in the watershed: fecal indicator bacteria (total coliforms (TC), fecal coliforms(FC)); nutrient parameters: nitrate (NO_3), ammonia (NH_3), organic nitrogen, total phosphorus; and one sediment parameter: turbidity. Water quality parameters collected for the Source Area program include the core field parameters listed above in addition to parameters of interest for target sub-watersheds. These additional parameters may include metals, oil and grease, and/or (Volatile Organic Compounds (VOC's). Fecal indicator bacteria for the Source Area program will be measured through total coliform and *E.coli* MPN/100mL using defined substrate methods. Nutrient and sediment parameters will be the same as the Trends program.

In addition to these water quality parameters or "response variables", descriptive or "explanatory variables" were collected. These include tidal stage, discharge, cumulative precipitation, and others. Because discharge measurements are often time consuming, and are problematic during both high- and low-flow conditions, use of existing stream-gauging stations, rating curves, installation of staff plates and estimates of flow are used where appropriate. Analytical methods will follow accepted procedures such as those outlined in the Standard Methods for the Examination of Water and Wastewater (Eaton et al., 2005) as outlined in the program QAPP.

A description of target parameters, and their significance for water quality and ecosystem health is offered with the results from Trends monitoring.

Sampling Frequency and Duration

Trend sampling is conducted on a weekly basis during the rainy season (late Fall, Winter and early Spring), and twice monthly during summer base flow conditions. During the first year (2007-08) of monitoring, weekly monitoring began on December 17, 2007 and continued through April 8, 2008. Twice monthly monitoring was conducted from April 22, 2008 through the end of the water year (Sept. 30, 2008). For the second water year (2008-09), twice-monthly sampling continued from October 1, 2008 through October 28, 2008. Wet-season, weekly sampling began on November 4, 2008 and continued through March 31, 2009. Twice-monthly, dry season sampling resumed on April 7, 2009 and continued through the end of the water year (September 30, 2009). During WY10, twice-monthly dry season sampling continued through October 6, 2009. Weekly sampling began on October 13th, 2009 and continued through May 18th,

2010. Twice-monthly sampling resumed on June 1, 2010 and continued through the end of the water year (September 30, 2010). For the WY11, weekly sampling resumed on October 19th, 2010 and continued through April 19th, 2011. For the current reporting year (WY12), weekly sampling began on November 1st, 2011 and continued through May 1st, 2012; twice-monthly sampling continued through the end of the water year, with the last sample collected on September 18th, 2012.

Weekly sampling more accurately captures changing conditions during the storm season and allows for a moving 5-week geometric mean for bacteria to be maintained. Dry season conditions have much less variation, and sampling every two weeks provides adequate data for analysis.

Sampling Locations

Trend sampling was conducted at 11 tributary sites in the watershed, and 4 Bay sites along the longitudinal transect of Tomales Bay. A list of Trends program sampling locations, along with location information (description, latitude/longitude, etc) is available in appendix B. Tributary sites are located at the lower end of tributary watersheds, often just upstream of their discharge to Tomales Bay, or to dependent streams.

Due to logistical limitations of partners sampling in the Bay, data collection for inner-, mid- and outer-Bay sites was limited to once-per-month sampling on the first Tuesday of each month (this sampling is concurrent with California DPH Shellfish Program sampling), typically only when the Bay is open to shellfish harvesting. Many sites were selected due to their inclusion in previous monitoring efforts through the RWQCB pathogen TMDL, and NPS water quality program. The existence of this legacy data, and its incorporation into our water quality database, will enable longer-term inference of water quality trends than could be accomplished by the data generated by this program alone.

Figure 3 – TBWC Trends Program Water Quality Monitoring Sites

Project Data Summary

The following sections offer detailed summary of watershed data from this program for the 2008-2012 water years. Sections includes rainfall and discharge (stream-flow) record and Trends Project results (site visits, summary statistics for field, nutrient, sediment and bacteria measurements)

Available Sources of Rainfall and Discharge Monitoring in the Watershed

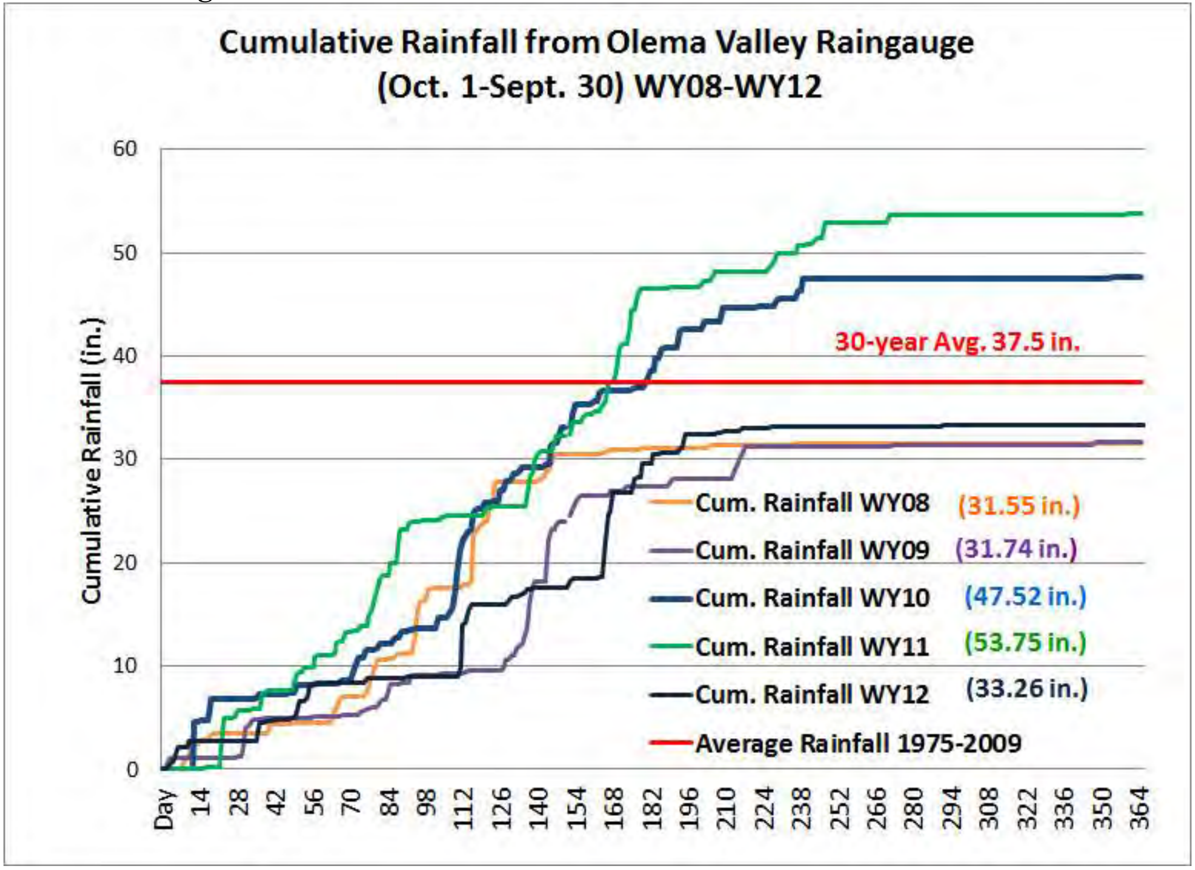
There are numerous rain gauges in the watershed, including a network maintained by MMWD, several gauges maintained by Marin County, and several by the National Park Service. There is a general orthographic trend of decreasing rainfall totals from South to North, and from West to East. For the sake of consistency, the rain gauge maintained by the NPS in the Olema Valley at the Point Reyes National Seashore headquarters is used in this report. Data from this station is available online at:
http://raws.wrh.noaa.gov/cgi-bin/roman/meso_base.cgi?stn=OVYC1&time=GMT *
*this station was decommissioned in early 2013, although NPS staff is working to restore the raingauge logging and transmission in advance of the first WY14 rains.

Discharge is monitored in the watershed by the US Geological Survey (USGS) at two sites on Lagunitas Creek (11460400 at Samuel P. Taylor State Park and 11460600 near Point Reyes Station), and one site on Walker Creek (11460750 at Walker Creek Ranch near Marshall). Data from these gauges are available in real-time at:
http://waterdata.usgs.gov/ca/nwis/rt. In addition, MMWD maintains a streamgauge on San Geronimo Creek (http://www.balancehydrologics.com/geronimo/creek/index.php), and the National Park Service maintains a streamgauge on Olema Creek (data not available online). Approximately 25% of the Lagunitas Creek watershed area, 60% of the Walker Creek watershed area, and all of the coastal drainages on the east and west shores of Tomales Bay are ungauged (Fischer et al. 1996)

Rainfall and Discharge Record

The rainfall during water-years 2008, 2009, 2010, 2011 and 2012 (measured at the NPS weather station at the Olema Valley headquarters) was 31.55 inches, 31.74 inches, 47.52 inches, 53.75 inches and 33.26 inches respectively. The cumulative rainfall for the first two, and the last reporting years (WY08, WY09 and WY12) were each lower than the 30-year average of 37.5 inches (NPS, unpublished data), although this 30-year average conceals the significant variance in average annual rainfall which ranges from about 17 inches in 1976-77 to about 82 inches in 1982-83. The cumulative rainfall for WY10 exceeded the 30-year average by almost 27-percent and rainfall for WY11 exceeded the average by 43%.

Figure 4 – Cumulative Rainfall for Water-Years 2008-2012



Data compiled from: Rainfall: University of Utah, MesoWest Station OVYC1, courtesy of BLM and NPS. Accessed at: http://raws.wrh.noaa.gov (The station was deactivated 7/1/2013)

Stream-flow from the first four years of the program is summarized in the following figures. The mean daily discharge record from the USGS stream gauge station (11460600 - Lagunitas Creek near Point Reyes Station) is used to represent the hydrograph for each water year. Two other USGS stream gauge stations are maintained in the watershed (station 114060400 on Lagunitas Creek at Samuel P. Taylor State Park and station 11460750 on Walker Creek), and data from these stations is used to report instantaneous discharge at Trends stations LAGSPT and WKR2 respectively. In addition, the Marin Municipal Water District (MMWD) operates a stream gauge on San Geronimo Creek that is located at a TBWC Trend station (Data from this gauge is used to report instantaneous discharge at our station SG1).

As can be seen by the magnitude of the discharge from water-year 2009, dry conditions prevailed and likely influenced the results of water quality monitoring. The rainfall from water-years 2010 and 2011 illustrates significantly more rainfall than the first two years of monitoring. These conditions resulted in an increased number of storm-related samples for these two water years, and the consequences are reflected in the frequency and magnitude of elevated levels of sediment and bacteria in particular. The rainfall from water year 2012 was below average, similar to water years 2008 and 2009. These results are detailed in the following section.

Figure 5-Discharge and Rainfall WY08

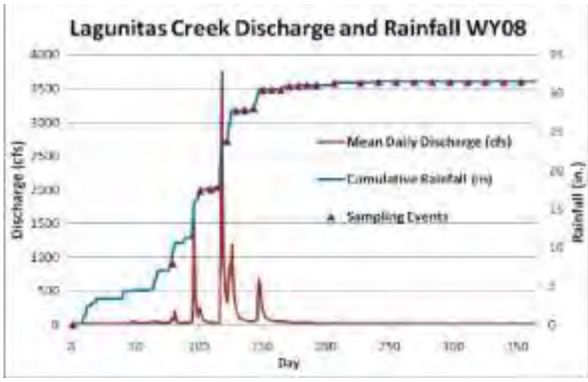


Figure 6-Discharge and Rainfall WY09

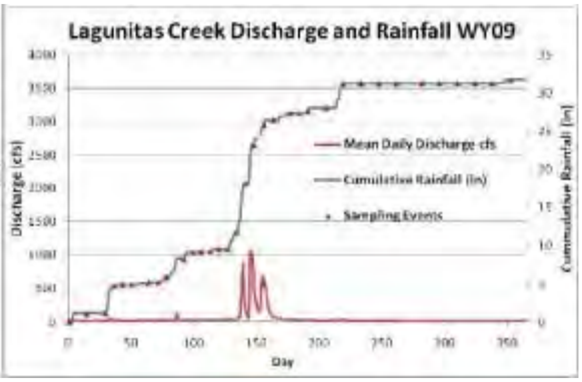


Figure 7 – Discharge and Rainfall WY10

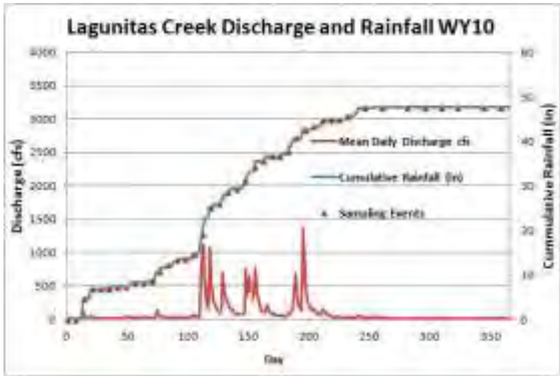


Figure 8 – Discharge and Rainfall WY11

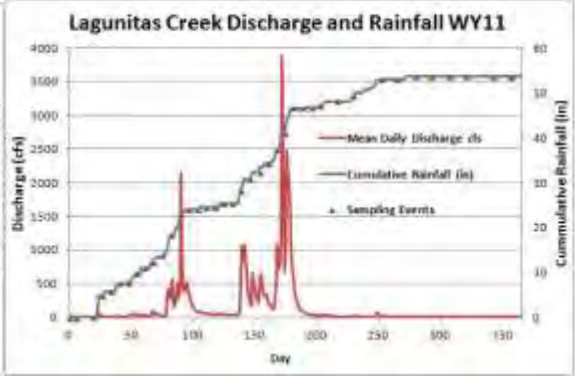
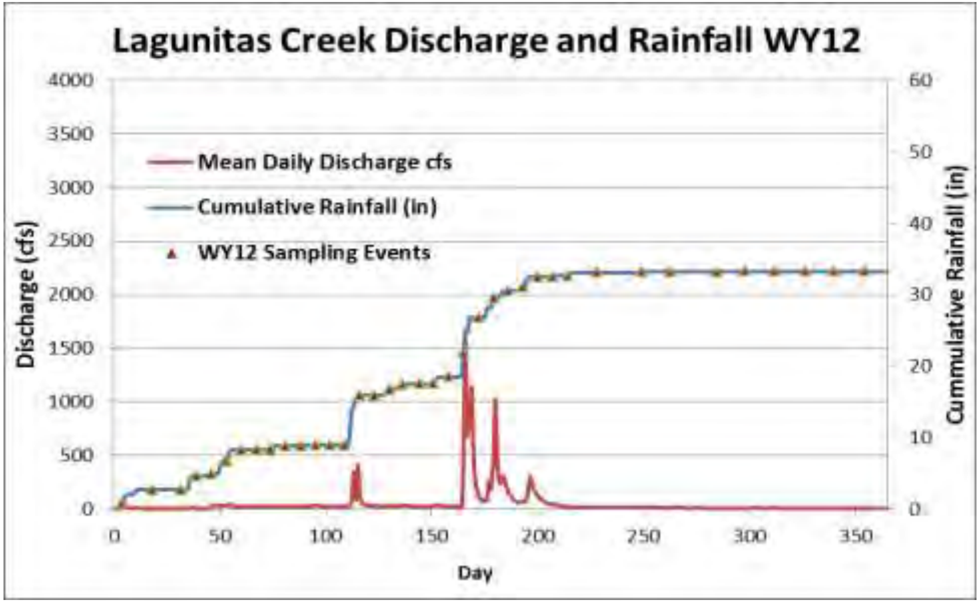


Figure 9 – Discharge and Rainfall WY12



Note for Figures 5-9: Data compiled from: Rainfall: University of Utah, MesoWest Station OVYC1, courtesy of BLM and NPS. Accessed at: http://raws.wrh.noaa.gov (The station was deactivated 7/1/2013). Stream gauge/Discharge: Courtesy of United States Geological Survey (USGS), station 11460600 Lagunitas Creek near Point Reyes Station. Accessed at: http://waterdata.usgs.gov/nwis/uv?11460600

Trends Project Results

Sampling at Trends Program sites began in December 2007 and continued through September 2012. As described in the previous section, each site is visited weekly during the wet season, and twice monthly during base-flow conditions (sampling frequency is reduced when regular, significant rains are over for the year). Frequency is increased again with the arrival of a significant rain event in October or November which causes a significant response in stream-flow or runoff conditions. The following section describes the results of Trends Program sampling during the 2012 water year (October 1, 2011-September 30, 2012). There is a short description of each sampled sub-watershed then results of field, nutrient, sediment and bacteria analysis. The results include descriptive statistics for each site and parameter for the WY12 season, as well as sampling results with box-plots by water year (WY08-WY12), and time-series graphs for most parameters. Additional graphs are included in appendix D of this report.

A summary of sites, the period of record for the current water year, and the number of samples per site are shown in Table 1 below. Tables for the site visits during the 2008-2011 water years are available in the appendix C of this report.

Table 1 – Site Visits for 2012 Water Year

WY12 Site Visit Summary

Site Name	Site Type	Description	Period of Record	Number of Sampling Visits
Lagunitas Creek				
SG1	Tributary Site	San Geronimo Creek at Lagunitas Rd	10/4/11-9/18/12	38
LAGSPT	Mainstem Stream Site	Lagunitas Creek in SPT State Park (at USGS streamgage)	10/4/11-9/18/12	38
OLM11	Tributary Site	Olema Creek at NPS streamgage	10/4/11-9/18/12	38
LAG1	Mainstem Stream Site	Lagunitas Creek at Hwy. 1 (Green Bridge)	10/4/11-9/18/12	38
West Shore				
FV1	Mainstem Stream Site	First Valley Creek at SFD Blvd.	10/4/11-9/18/12	38
WG1	Mainstem Stream Site	White Gulch upstream of Bay inflow	10/4/11-6/19/12	31
East Shore				
MC1	Mainstem Stream Site	Millerton Gulch at upstream CA State Park boundary	10/18/11-7/10/12	32
MP36.17	Mainstem Stream Site	Reference stream at Hwy. 1	10/4/11-9/18/12	38
Walker Creek				
WKR2	Mainstem Stream Site	Walker Creek at Walker Creek Ranch	10/4/11-9/18/12	38
WKR1	Mainstem Stream Site	Walker Creek at Hwy.1	10/4/11-9/18/12	38
KYS1	Tributary Site	Keys Creek at Hwy. 1	10/4/11-6/19/12	32
Tomales Bay Sites				
TB2	Outer Bay Site	Bay Site near Walker Crk input	10/4/11-9/4/12	11
TB4	Mid-Bay Site	Bay Site North of Marshall	10/4/11-9/4/12	10
TB11	Inner Bay Site	Bay site near Millerton Point	10/4/11-7/10/12	8
LAG6	Wetlands/Bay Interface	Lagunitas Creek downstream of levees	10/4/11-9/18/12	38

Detailed trends results by sub-watershed

A basic statistical analysis of Trends Program data through WY12 is shown in the following section with results from the year-to-year comparison by site. The analysis is presented for each type of measurement (i.e. field measurements, nutrient, bacteria and sediment) for each major sub-watershed to Tomales Bay. In the Watershed Description (above), Figure 1 shows the delineation of monitored subwatersheds for this program.

Field Parameters Results for Trends Program WY08-WY12

Field measurements made by this program are standard water quality parameters recommended for monitoring by both the US Environmental Protection Agency (EPA) and the US Geological Survey (USGS). These parameters are crucial not only to describe *in*-situ environmental conditions, but also to determine chemical characteristics of laboratory-analyzed parameters. Measurements were made using calibrated single-, or multi-parameter meters. This program uses a YSI85 to measure temperature, conductivity, and dissolved oxygen; and an Oakton or YSI meter for pH measurements. All equipment calibrations are conducted and logged according to the protocol established by our monitoring plan and QAPP (Carson 2007).

Temperature – specifically water temperature- is critical for the reproduction and survival of cold-water fish, amphibian and benthic invertebrate species that are present in the watershed. The thermal tolerance ranges for coho salmon are 12-19 degrees centigrade, while steelhead trout can tolerate warmer temperatures ranging from 13-21 degrees centigrade. Ideal temperatures for rearing juvenile coho salmon range from 10-15.6-degrees C (Armour, 1991). Temperature also has important implications for dissolved oxygen levels in the water, with lower temperatures able to store more oxygen for use by aquatic organisms. Temperature also plays a role in both pH and the level of toxic un-ionized ammonia. Higher temperatures and higher pH values result in higher amounts of the toxic ammonia.

Conductivity – is the measurement of the ability of ions in an aqueous solution to carry electrical current due to the levels of dissolved salts. It is essentially an estimate of dissolved ionic “pollution” in a sample. Results are reported in microSiemens per centimeter (uS/cm). Specific Conductance is defined as the conductivity normalized to 25-degrees centigrade. This value is the standard reporting value because it can be compared across samples without knowing the water temperature. This value is also used to calculate and report a value for salinity. Elevated conductivity is indicative of a significant salt source and, because of osmotic processes, has implications for aquatic organisms’ ability to regulate water concentrations in their bodies. Conductivity in our watershed streams is affected primarily by the geology of the area through which the water flows, depending on whether the substrate does or does not ionize (dissolve into ionic components) when washed into the water.

Dissolved Oxygen – is a measure of the oxygen available in the water for aquatic organisms, and is reported as a concentration (mg/L) or as a percent saturation (%). The oxygen levels are highly dependent on water temperature with warmer water able to hold less oxygen than colder water. Another factor that affects the level of oxygen in water is the turbulence of flow, with riffles and falls increasing the atmospheric oxygen introduced into the water column. The RWQCB’s Basin Plan (RWQCB 2010) established water quality objectives for warm and cold water habitat at 5.0mg/L and 7.0 mg/L, respectively.

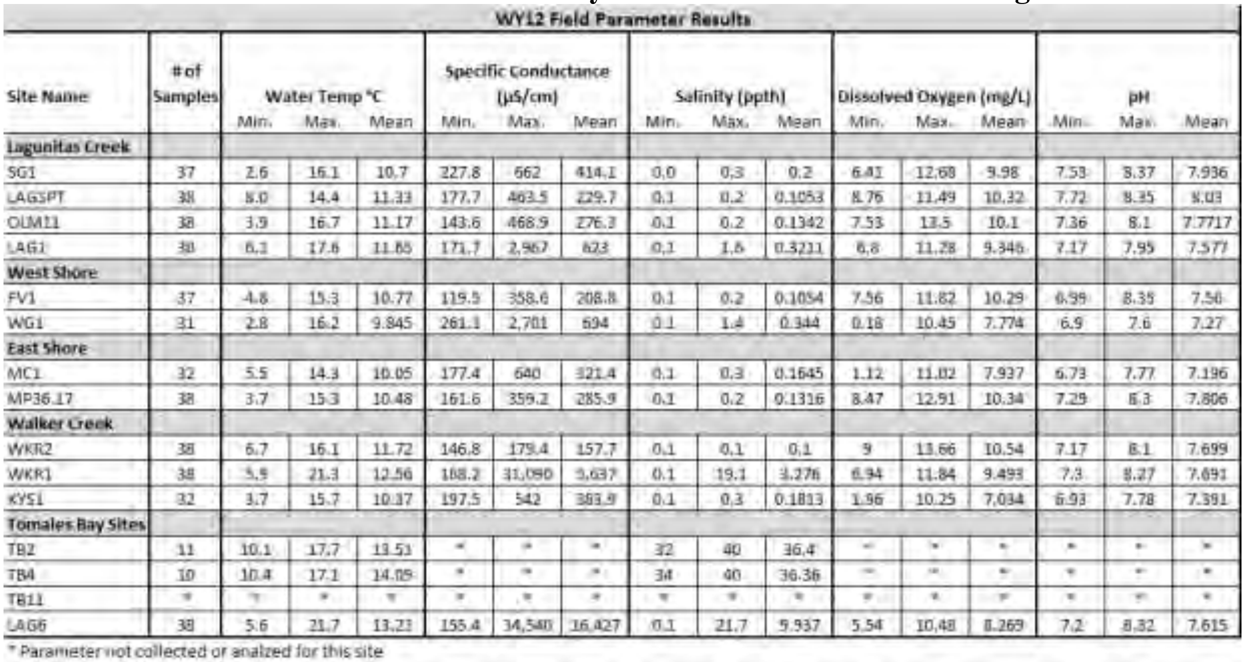
pH – is a measure of the acidity or basicity of a solution. It is a proxy measure for the activity of hydrogen (H^+) ions in the solution, and is measured relative to standard solutions of known pH. The pH of water bodies has significant implications for natural chemical processes. For example, under low pH conditions, toxic elements such as aluminum are more easily leached into the water from surrounding soils. pH also plays an important role in ammonia chemistry, with higher pH values leading to the conversion of ammonium (NH_4^+) to more toxic un-ionized ammonia

(NH3). The RWQCB’s Basin Plan (RWQCB 2010) established water quality objectives for pH as less than 8.5 and greater than 6.5.

Trend Program Field Parameter Results WY08-WY12

The following table shows results for field parameter measurements taken during the 2012 water year. The minimum, maximum and mean values for each field measurement (water temperature, specific conductance, salinity, dissolved oxygen and pH) are shown for each station. Summary tables for WY08, WY09, WY10 and WY11 are available in Appendix C.

Table 2 – WY12 Field Parameter Results by Station for Trends Monitoring



WY12 Field Parameter Results

Site Name	# of Samples	Water Temp °C			Specific Conductance (µS/cm)			Salinity (ppth)			Dissolved Oxygen (mg/L)			pH		
		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Lagunitas Creek																
SG1	37	2.6	16.1	10.7	227.8	662	414.1	0.0	0.3	0.2	6.41	12.68	9.98	7.53	8.37	7.936
LAGSPT	38	8.0	14.4	11.33	177.7	463.5	229.7	0.1	0.2	0.1053	8.76	11.49	10.32	7.72	8.35	8.03
OLM11	38	3.9	16.7	11.17	143.6	468.9	276.3	0.1	0.2	0.1342	7.53	13.5	10.1	7.36	8.1	7.7717
LAG1	38	6.1	17.6	11.85	171.7	2,967	623	0.1	1.6	0.3211	6.8	11.28	9.346	7.17	7.95	7.577
West Shore																
FV1	37	4.8	15.3	10.77	119.5	358.6	208.8	0.1	0.2	0.1054	7.56	11.82	10.29	6.99	8.35	7.56
WG1	31	2.8	16.2	9.845	261.1	2,701	694	0.1	1.4	0.344	0.18	10.45	7.774	6.9	7.6	7.27
East Shore																
MC1	32	5.5	14.3	10.05	177.4	640	321.4	0.1	0.3	0.1645	1.12	11.02	7.937	6.73	7.77	7.196
MP36.17	38	3.7	15.3	10.48	161.6	359.2	285.9	0.1	0.2	0.1316	8.47	12.91	10.34	7.29	8.3	7.806
Walker Creek																
WKR2	38	6.7	16.1	11.72	146.8	179.4	157.7	0.1	0.1	0.1	9	13.66	10.54	7.17	8.1	7.699
WKR1	38	5.9	21.3	12.56	108.2	31,090	3,637	0.1	19.1	3.276	6.94	11.84	9.493	7.3	8.27	7.691
KYS1	32	3.7	15.7	10.37	197.5	542	383.9	0.1	0.3	0.1813	1.96	10.25	7.034	6.93	7.78	7.391
Tomales Bay Sites																
TB2	11	10.1	17.7	13.51	*	*	*	32	40	36.4	*	*	*	*	*	*
TB4	10	10.4	17.1	14.09	*	*	*	34	40	36.36	*	*	*	*	*	*
TB11	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
LAG6	38	5.6	21.7	13.23	155.4	34,540	16,427	0.1	21.7	9.937	5.54	10.48	8.269	7.2	8.32	7.615

* Parameter not collected or analized for this site

Results show that water temperature exceeded ideal conditions for coho and steelhead during the year at several stations, including several sites in the Lagunitas watershed, and one in the Walker Creek watershed. But, because field measurements of temperature do not represent the diurnal or seasonal range of conditions at the sites, these measurements are inadequate to evaluate the environmental conditions for salmonids. We have placed temperature loggers (Onset – HOBO® Water Temp Pro v2) at seven of the Trend Program sites (SG1, LAGSPT, OLM11, LAG1, FV1, MP36.17 and WKR2) to evaluate the long-term temperature cycles at sampling locations.

Salinity results show the annual range of salinities at each site. Some sites (WG1, MC1, KYS1) are on intermittent streams whose salinity increases as the freshwater inflow slows or stops. Other sites (WKR1, LAG1, LAG6, and WG1) are under some degree of tidal influence, reflected in the wider range of measured values.

Mean measurements of dissolved oxygen for all sites do not fall below the objective of 7 mg/L. However, minimum measurements at WG1, MC1, KYS1 are reflective of low oxygen conditions in low-, to no-flow conditions in summer. Of note, were low dissolved oxygen measurements in San Geronimo, Lagunitas and Walker Creeks that fell below the objective of 7 mg/L. All were taken during summer low-flow conditions, and represent conditions at the sampling point, not necessarily in refuge habitat such as shaded pools or undercut banks that may be utilized by salmonids during periods of stress.

Measurements of pH show that all measurements were below the upper limit of 8.5 established by the RWQCB in the Basin Plan (2007). However, some measurements fell below the lower limit of 6.5 at times during the year. The mean pH values for all sites were well within the objective range throughout this water year.

The graphs below show (boxplots) of field parameters for each site, each water year, by subwatershed grouping (Walker, Lagunitas, Coastal tributaries and Bay sites). A boxplot displays information about the range and distribution of data within the range (see figure at right). For the graphs in this report, the whiskers extending above and below the box are 1.5-times the middle 50% range box, with outliers shown by the asterisks (*). This treatment, which is a common variation on traditional boxplots whose whiskers extend to the minimum and maximum values, allows for the identification of outliers and extreme outliers that demonstrate the distribution and frequency of such results. To present the data in the most useful form, outliers are omitted from the box-plot graphs below, but are included in graphs in Appendix D of this document.

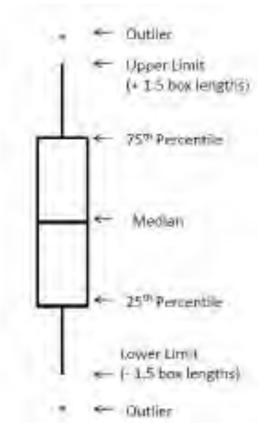


Figure 10 – Lagunitas Creek Watershed Field Parameters by Water Year

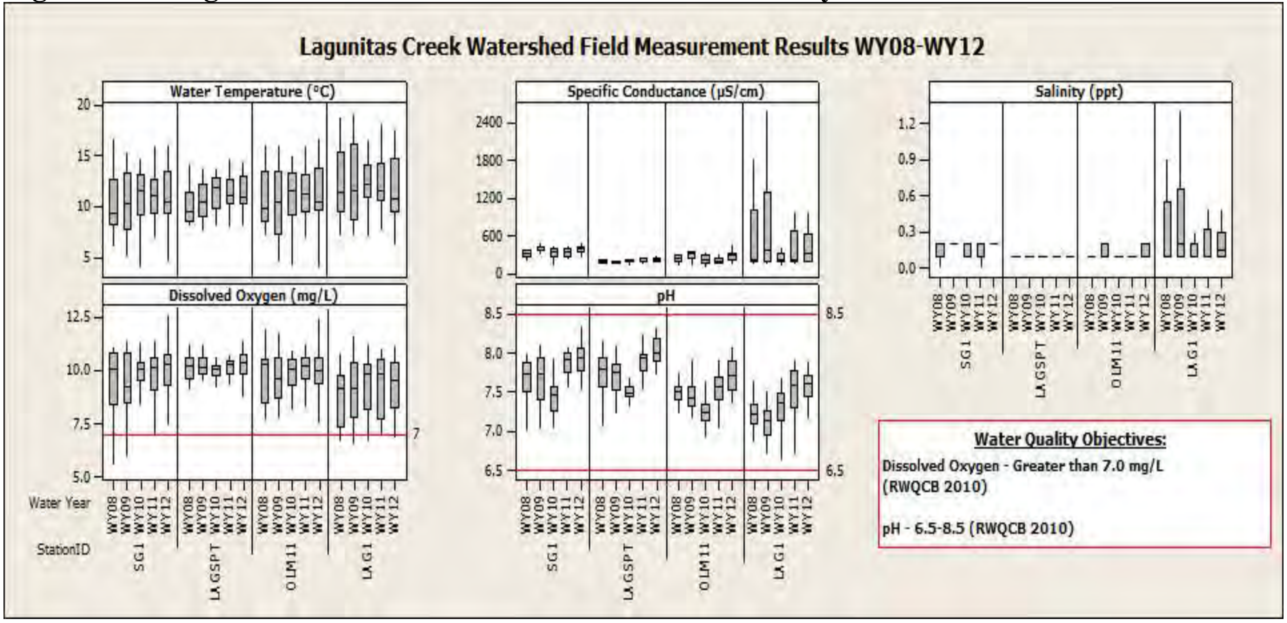


Figure 11 – East & West Shore Tributaries Field Parameters by Water Year

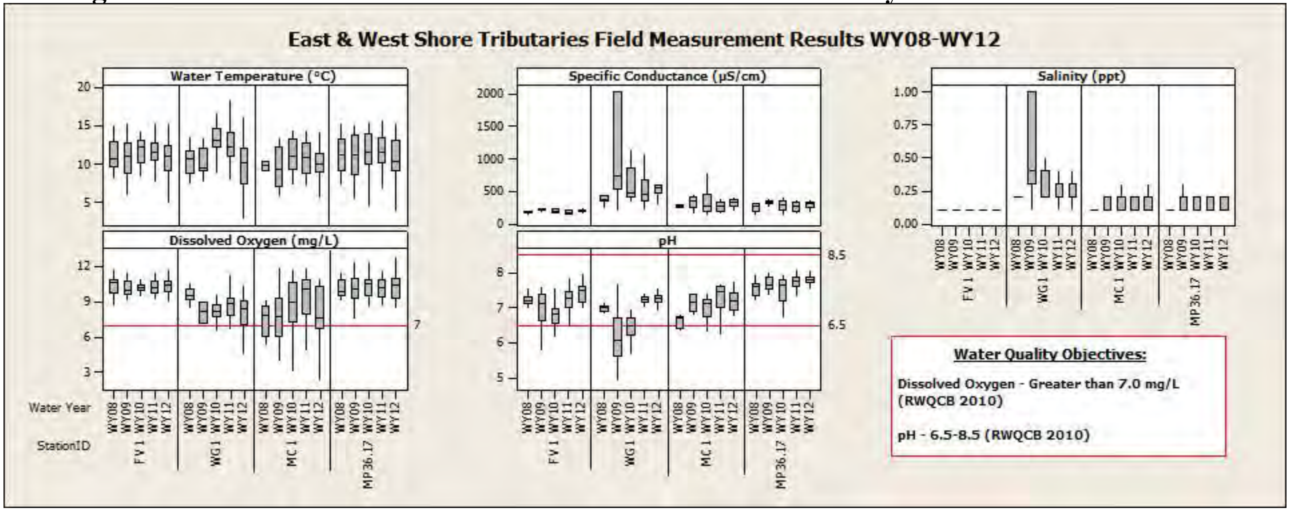


Figure 12 – Walker Creek Watershed Field Parameters by Water Year

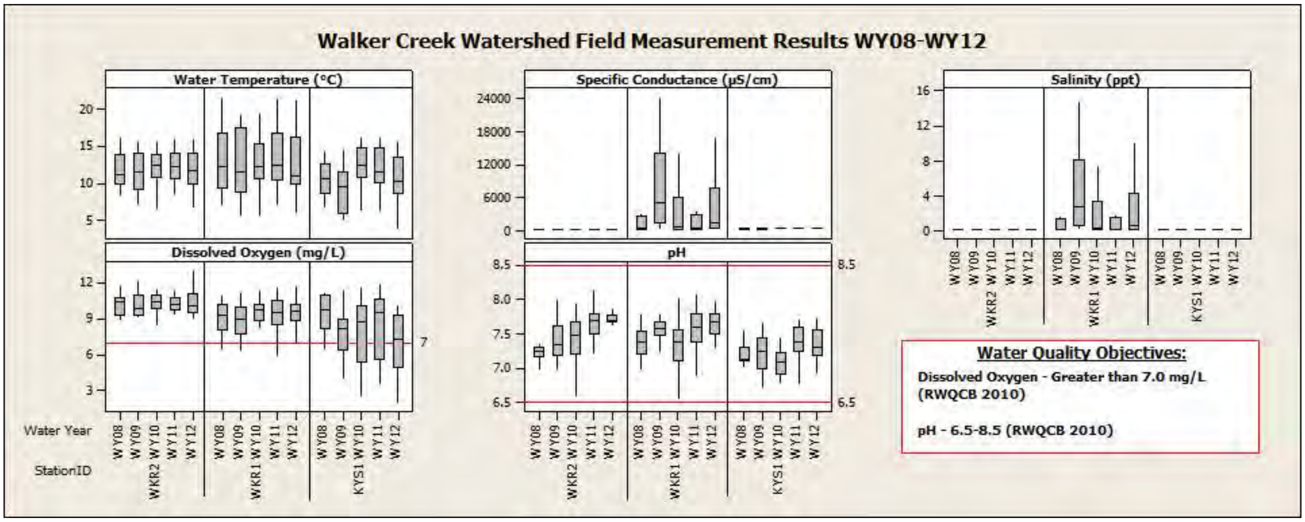
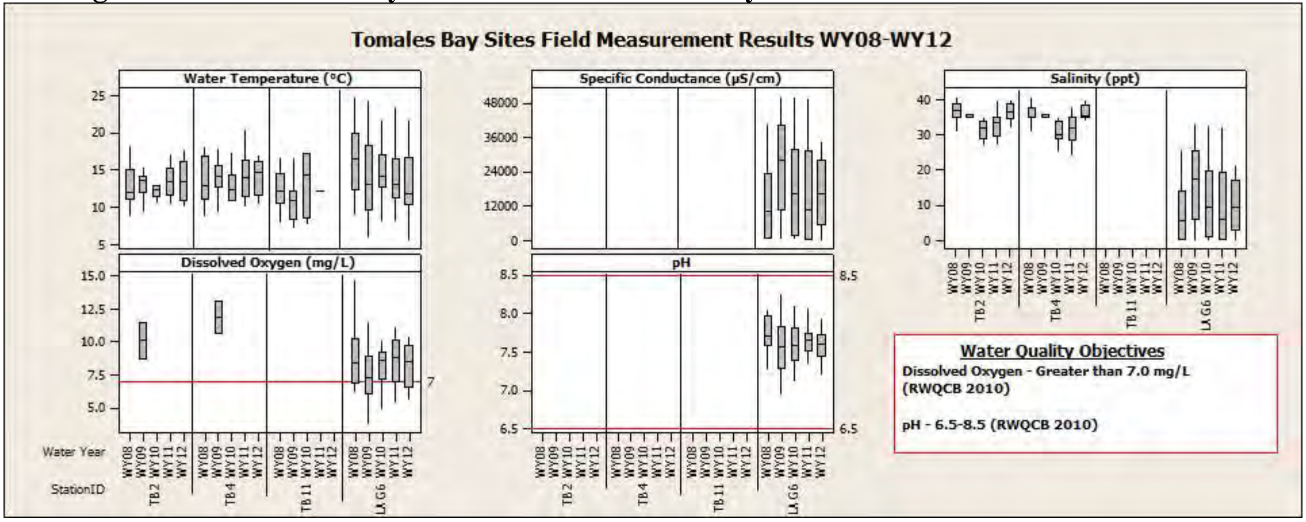


Figure 13 – Tomales Bay Sites Field Parameters by Water Year



Field parameters are not measured regularly at TB2, TB4, TB11 sites..

Nutrient Parameters Results for Trends Program WY08-WY12

Nutrient parameters measured by this program focus on nitrogen and phosphorus as one of these two is usually the limiting factor for primary production in aquatic systems. With the exception of ammonia, there are no criteria established by State regulators for nutrient levels in streams, but the EPA has recommended criteria for nutrient levels in regional rivers and streams that is included with the appropriate parameters below.

Nitrogen is an abundant nutrient in our watershed tributaries and in the Bay. The dynamics of the nitrogen cycle, and the relative abundance of each form, can provide additional information about the types of sources and impacts on the aquatic system. Natural sources of nitrogen in the watershed include decomposing organic material, human and animal waste, and fertilizers. The Trends Program monitored concentrations of nitrate (NO_3) and total Kjeldahl nitrogen (TKN) for the entire length of the monitoring program, but also monitored ammonia for the first three years of the program (WY08-WY10). Nitrate is the most stable, and most abundant, form of dissolved nitrogen, and Total Kjeldahl Nitrogen is the sum of organic nitrogen and ammonia. Sources of nitrates include chemical fertilizers, animal (domestic, livestock and wildlife) waste, human waste from compromised septic systems or treatment system spills, as well as decomposed ammonia, nitrite and organic nitrogen. Nitrate is very soluble and is flushed out of soils relatively easily. The main sources of organic nitrogen are decomposing organic material like vegetation (leaf litter, plants, roots, etc.), animals, etc. Organic nitrogen is often associated with soil particles, increasing with erosion and sediment-laden runoff. In general, ammonia is very short-lived (though potentially lethal) in aquatic systems, quickly undergoing chemical transformation to nitrite (NO_2), then to nitrate (NO_3). The consequence of this is that its detection usually suggests a proximate source such as livestock and wildlife.

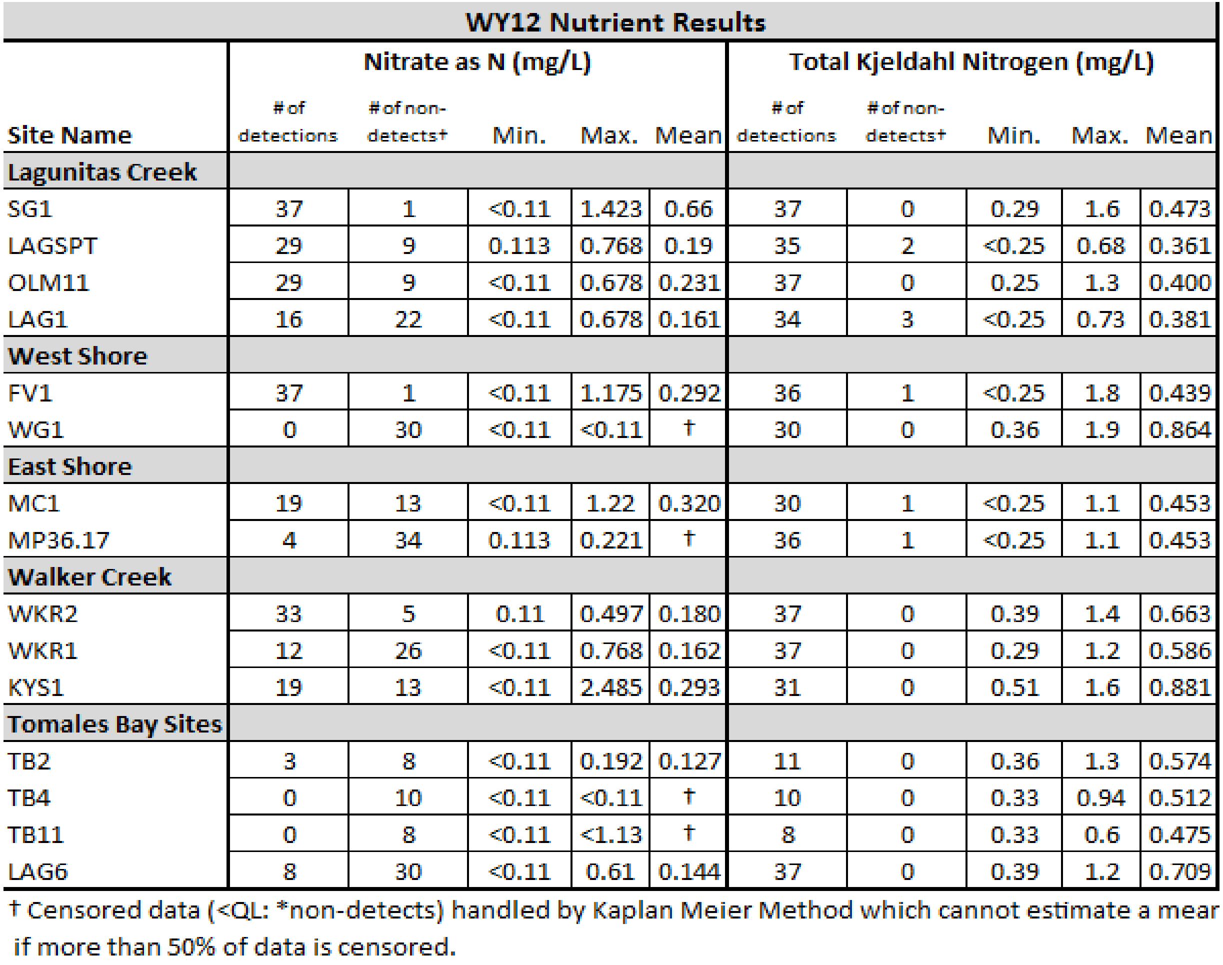
Nitrate (NO_3)– is the most common form of nitrogen found in surface waters. It is essential to biotic production. Depending on the system, either nitrogen or phosphorus is the nutrient limiting primary productivity. When there is an excess of nitrogen is present, increased production of algae or other aquatic plants may result. Where algal blooms occur, the productivity leads to super-saturated levels of dissolved oxygen, as the algae die, their decomposition consumes most of the oxygen in the system, leading to fish kills. Nitrate is very responsive to storm events, being mobilized by runoff from sinks such as fertilized areas, ponds or lagoons and being delivered to surface waters by overland or shallow sub-surface flow. The State of California has no established numeric water quality criteria for nitrate in surface waters, but the US EPA has established a numeric criterion only for human consumption of nitrate at 10mg/L. The US EPA has also recommended total nitrogen reference criteria for states and tribes to use in established their own regional criteria. The Tomales Bay watershed is in aggregate ecoregion III, which has a total nitrogen reference criteria of 0.38 mg/L, and in subregion 6 which has a slightly higher total nitrogen reference criteria of 0.50 mg/L (both based on the 25th percentile over 10 years) (EPA 2000). Because nitrogen pollution is a problem of accumulation in the ecosystem rather than direct toxicity to particular organisms, there has been little further guidance developed for acceptable levels in local streams. Results from nitrate analysis are reported as mg/L of Nitrogen, enabling the comparison of nitrogen levels across chemical forms of nitrate, nitrite, TKN and ammonia.

Ammonia (NH_3) – is another important natural form of nitrogen. In general, ammonia is very short-lived (though potentially lethal) in aquatic systems, quickly undergoing chemical transformation to nitrite (NO_2), then to nitrate (NO_3) in well-oxygenated waters with neutral pH. The consequence of this is that its detection usually suggests a proximate source such as livestock and wildlife. Most ammonia in aquatic systems occurs in its' ionized (or charged) form of NH_4^+, but temperature and pH conditions control the conversion to the more toxic un-ionized form of NH_3. For example, at 15°C and pH 7.0 only 0.3% of total ammonia is un-ionized, while at pH 9.0, the un-ionized ammonia is 21% of the total. High levels of un-ionized ammonia is directly toxic to aquatic organisms, and, as it is converted to nitrate, it consumes dissolved oxygen in the water, adversely affecting aquatic life. The RWQCB's Basin Plan (RWQCB 2007) sets a criteria for un-ionized ammonia in surface waters as an annual median <0.025 mg/L as N, and <0.16 mg/L as N in estuarine waters. Results from ammonia analysis are reported as mg/L of nitrogen, enabling the comparison of nitrogen levels across chemical forms of nitrate, nitrite, TKN and ammonia. Because had a very low number of detections of ammonia, and our contract laboratory was unable to provide more sensitive analysis, the program dropped analysis of ammonia during WY11. However, our monitoring data showed evidence of occasional and at least one time, lethal, ammonia levels in target streams.

Total Kjeldahl Nitrogen (TKN)– is the sum of organic nitrogen and ammonia in the sample. By adding TKN and nitrate/nitrite results, the total nitrogen can be calculated. This program does not measure nitrite levels, but because nitrite is quickly oxidized to nitrate in the environment, total nitrogen calculation can be *estimated* using program data. The main sources of organic nitrogen are decomposing organic material like vegetation (leaf litter, plants, roots, etc.), animals, etc. Organic nitrogen is often associated with soil particles, increasing with erosion and sediment-laden runoff. There are no numeric water quality criteria established for TKN in surface waters, though the EPA recommended criteria for total nitrogen in rivers and streams of aggregate ecoregion III is 0.38 mg/L and 0.50 mg/L in subregion 6, of which Tomales Bay is a part. Results from TKN analysis are reported as mg/L of N, enabling the comparison of nitrogen levels across chemical forms of nitrate, nitrite, TKN and ammonia.

Total Phosphorus (TP) – is a measure of the total phosphorus (P). Phosphorus is an essential element for primary productivity, and, like nitrogen, can be the limiting element in the environment (i.e. the availability of phosphorus governs the rate of growth of many organisms). Because there is no gaseous form of phosphorus, once it is in an aquatic system without a large outflow, it tends to cycle back and forth between the water column and the sediments without leaving the system (Horne and Goldman, 1994). The EPA recommends a total P criteria for Aggregate Ecoregion III streams and rivers of 0.02 mg-P/L (EPA 2000), with a range of reference conditions from 0.01-0.05 mg-P/L (EPA, 2000). Our monitoring of phosphorus in the watershed shows that levels are very low in watershed streams (most below our laboratories detection limit), suggesting that phosphorus is the limiting nutrient in this system. Because we were unable to get a lower detection limit for total phosphorus from our contract laboratory, the analysis was dropped during WY10.

Table 3– WY12 Nutrient Parameter Results for Trends Monitoring by Station

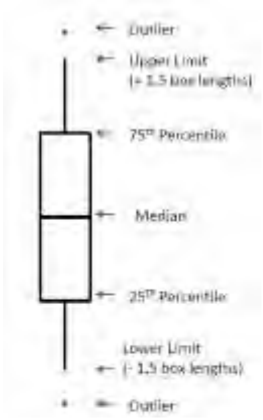


WY12 Nutrient Results

	Nitrate as N (mg/L)					Total Kjeldahl Nitrogen (mg/L)				
Site Name	# of detections	# of non-detects†	Min.	Max.	Mean	# of detections	# of non-detects†	Min.	Max.	Mean
Lagunitas Creek										
SG1	37	1	<0.11	1.423	0.66	37	0	0.29	1.6	0.473
LAGSPT	29	9	0.113	0.768	0.19	35	2	<0.25	0.68	0.361
OLM11	29	9	<0.11	0.678	0.231	37	0	0.25	1.3	0.400
LAG1	16	22	<0.11	0.678	0.161	34	3	<0.25	0.73	0.381
West Shore										
FV1	37	1	<0.11	1.175	0.292	36	1	<0.25	1.8	0.439
WG1	0	30	<0.11	<0.11	†	30	0	0.36	1.9	0.864
East Shore										
MC1	19	13	<0.11	1.22	0.320	30	1	<0.25	1.1	0.453
MP36.17	4	34	0.113	0.221	†	36	1	<0.25	1.1	0.453
Walker Creek										
WKR2	33	5	0.11	0.497	0.180	37	0	0.39	1.4	0.663
WKR1	12	26	<0.11	0.768	0.162	37	0	0.29	1.2	0.586
KYS1	19	13	<0.11	2.485	0.293	31	0	0.51	1.6	0.881
Tomales Bay Sites										
TB2	3	8	<0.11	0.192	0.127	11	0	0.36	1.3	0.574
TB4	0	10	<0.11	<0.11	†	10	0	0.33	0.94	0.512
TB11	0	8	<0.11	<1.13	†	8	0	0.33	0.6	0.475
LAG6	8	30	<0.11	0.61	0.144	37	0	0.39	1.2	0.709

† Censored data (<QL: *non-detects) handled by Kaplan Meier Method which cannot estimate a mear
if more than 50% of data is censored.

The following graphs (boxplots) show the results of nutrient monitoring (nitrate, total Kjeldahl nitrogen) at Trends Program sites by site for each subwatershed grouping. A boxplot displays information about the range and distribution of data within the range (see figure at right). For the graphs in this report, the whiskers extending above and below the box are 1.5-times the middle 50% range box, with outliers shown by the asterisks (*). This treatment, which is a common variation on traditional boxplots whose whiskers extend to the minimum and maximum values, allows for the identification of outliers and extreme outliers that demonstrate the distribution and frequency of such results. To present the data in the most useful form, outliers are omitted from the box-plot graphs below, but are included in graphs in Appendix D of this document.



Also, see Appendix D for graphs of nutrient parameter results for each site with each year graphed by water-year week to enable site-specific comparisons across water year.

Figure 14 – Lagunitas Creek Watershed Sites Nitrate Results by Water Year

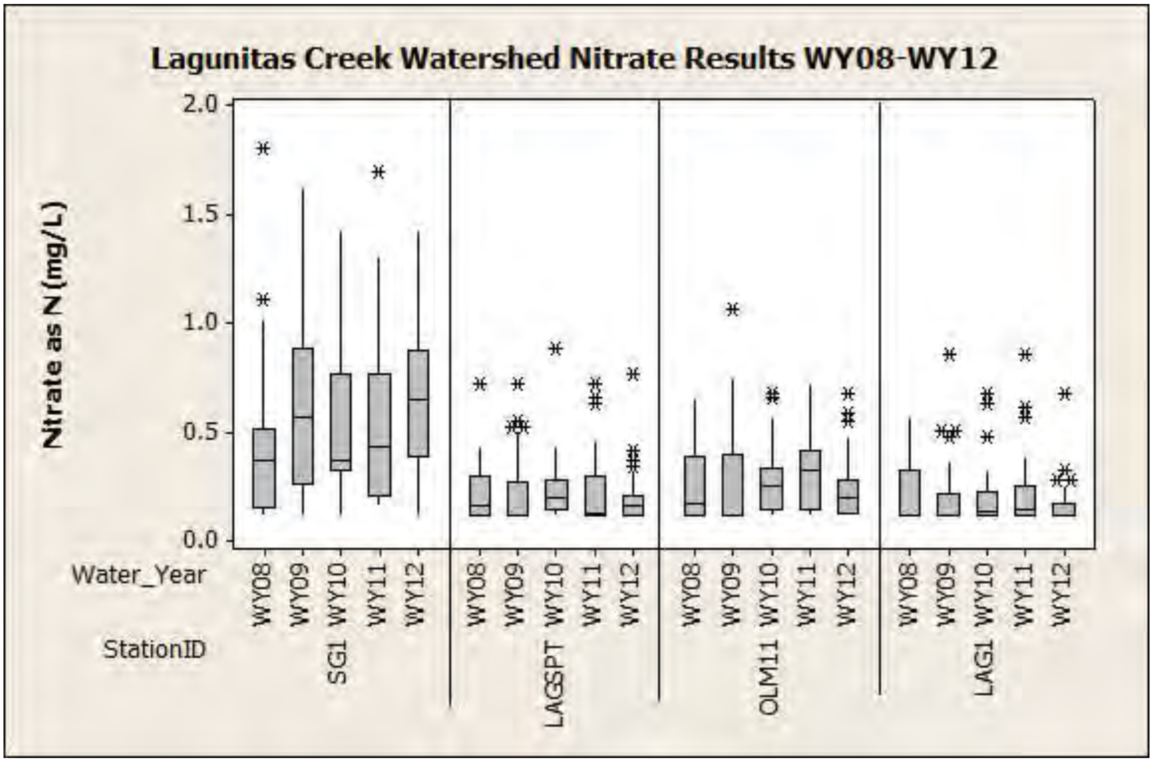


Figure 15 – Lagunitas Creek Watershed Nitrate (NO_3) Time Series WY08-WY12

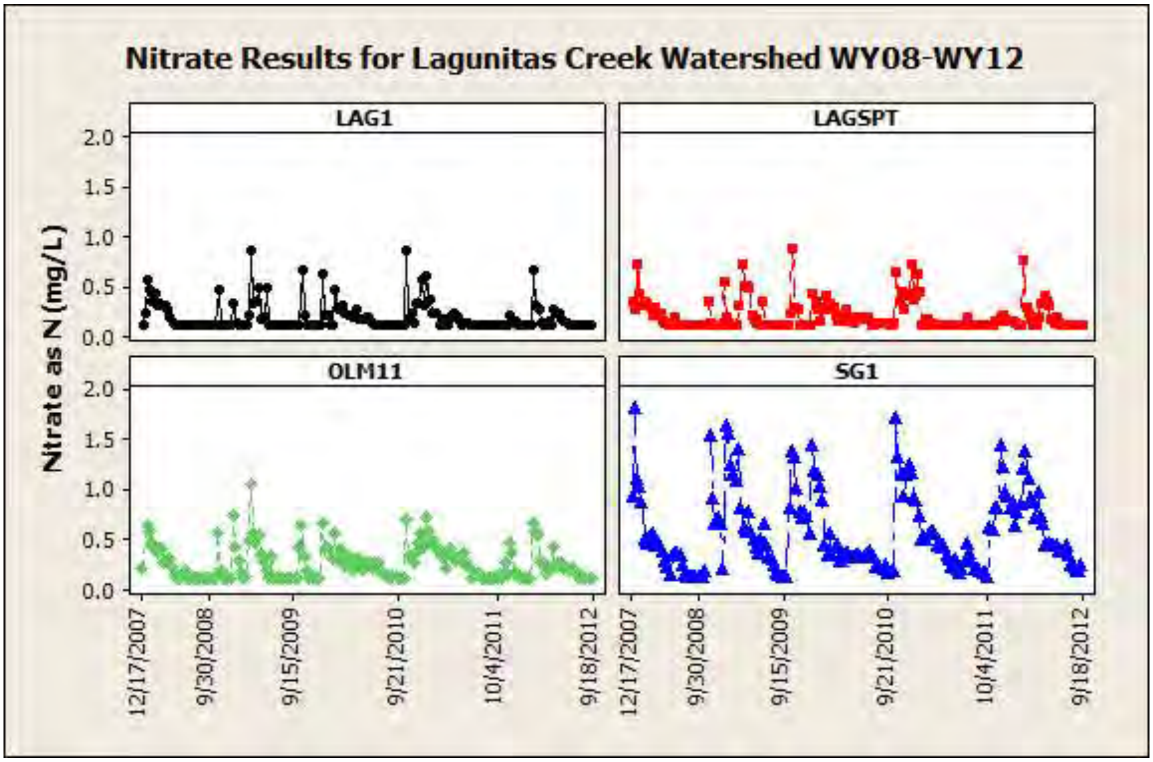


Figure 16 – Lagunitas Creek Watershed Sites TKN by Water Year

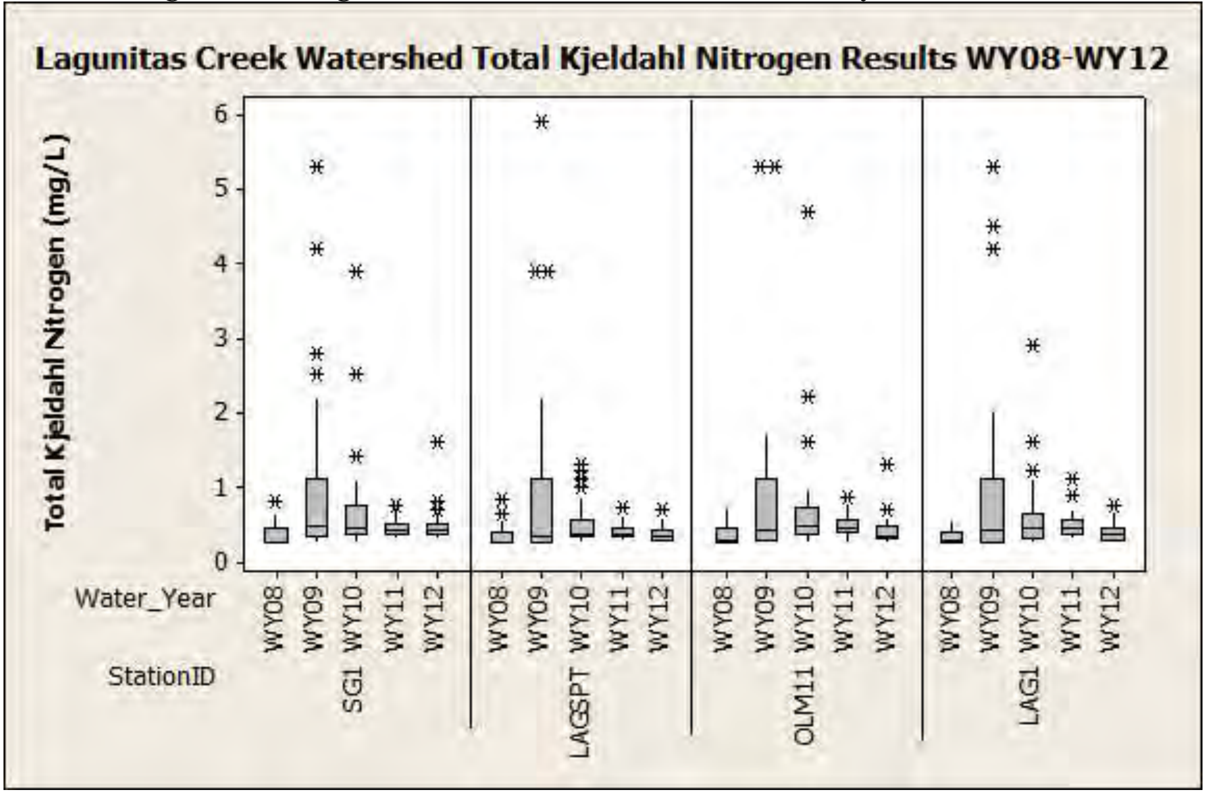
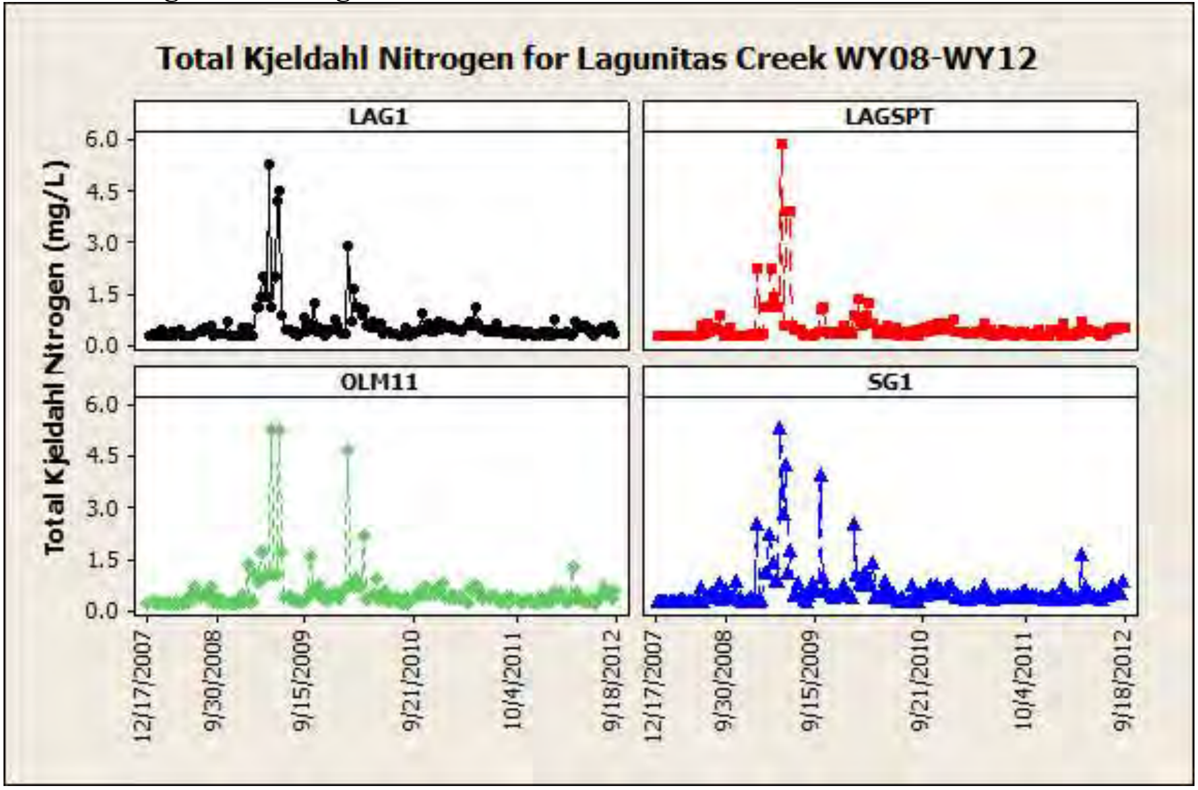


Figure 17 – Lagunitas Creek Watershed TKN Time Series WY08-WY12



Nutrient results from sites in the Lagunitas Creek watershed demonstrate that the watershed as a whole, and one site in particular, shows elevated nutrient levels, mainly nitrogen, especially during storm events. The box-plots and time-series graphs of nitrate (NO_3 as N) shows that the site in San Geronimo Creek (SG1) has the highest mean, widest range, and highest frequency of elevated values for nitrate in the Lagunitas Creek watershed. This suggests a persistent loading source of nitrate in the San Geronimo Creek watershed. Potential sources include the well-documented presence of compromised septic systems (TBWC 2007, Fall Creek Engineering 2007) and chemical fertilizer runoff from home gardens or the golf course. The results total Kjeldahl nitrogen (TKN) analysis shows relatively low levels, with significant elevation of concentration during storm events. Peak loading events from all sites in the watershed are of similar magnitude, with little signal of dilution occurring from upstream to downstream. These results suggest that there is loading of organic nitrogen (the main component of TKN) throughout the watershed, mainly during major storm events. Organic nitrogen is frequently associated with sediment particles in the water column. This suggests that the hydrologic response of our watershed tributaries and associated runoff mobilizes sediment and nutrients during winter storm events, and that this response results in nitrogen loading throughout the Lagunitas Creek watershed.

Figure 18 – East & West Shore Tributary Sites Nitrate Results by Water Year

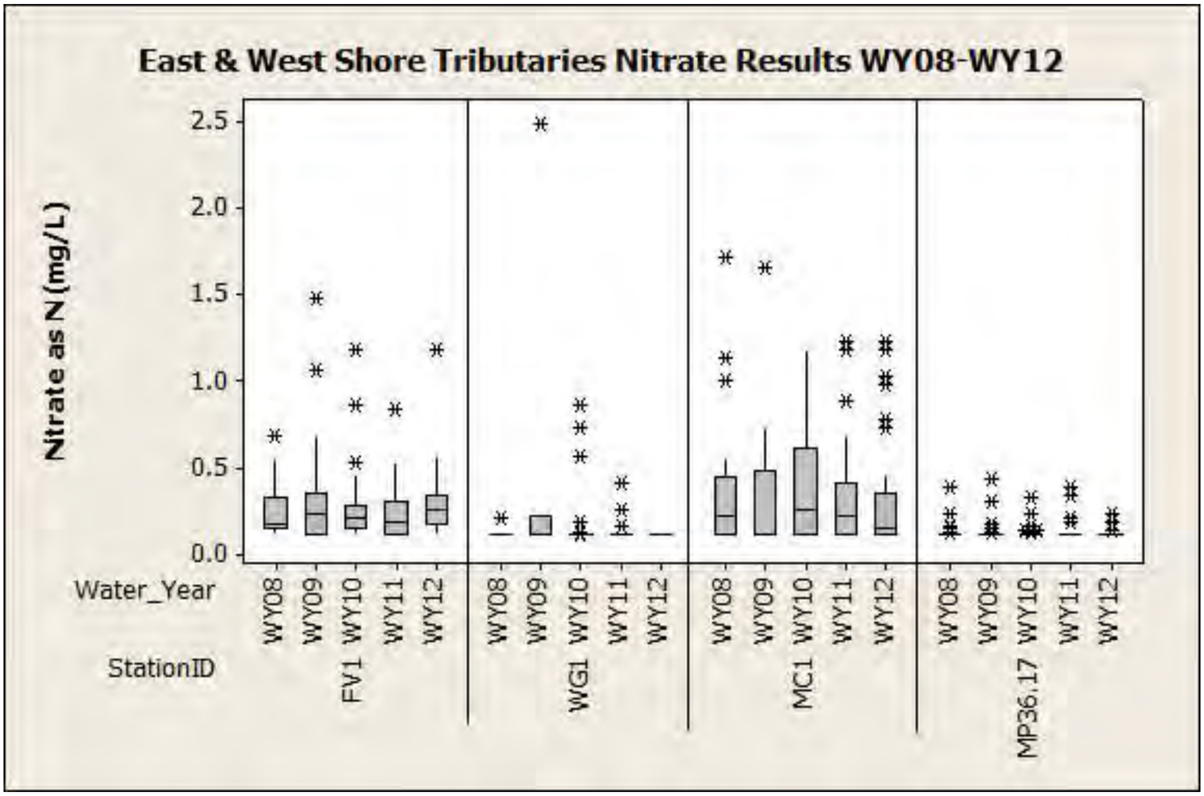


Figure 19 – East & West Shore Tributary Nitrate (NO_3) Time Series WY08-WY12

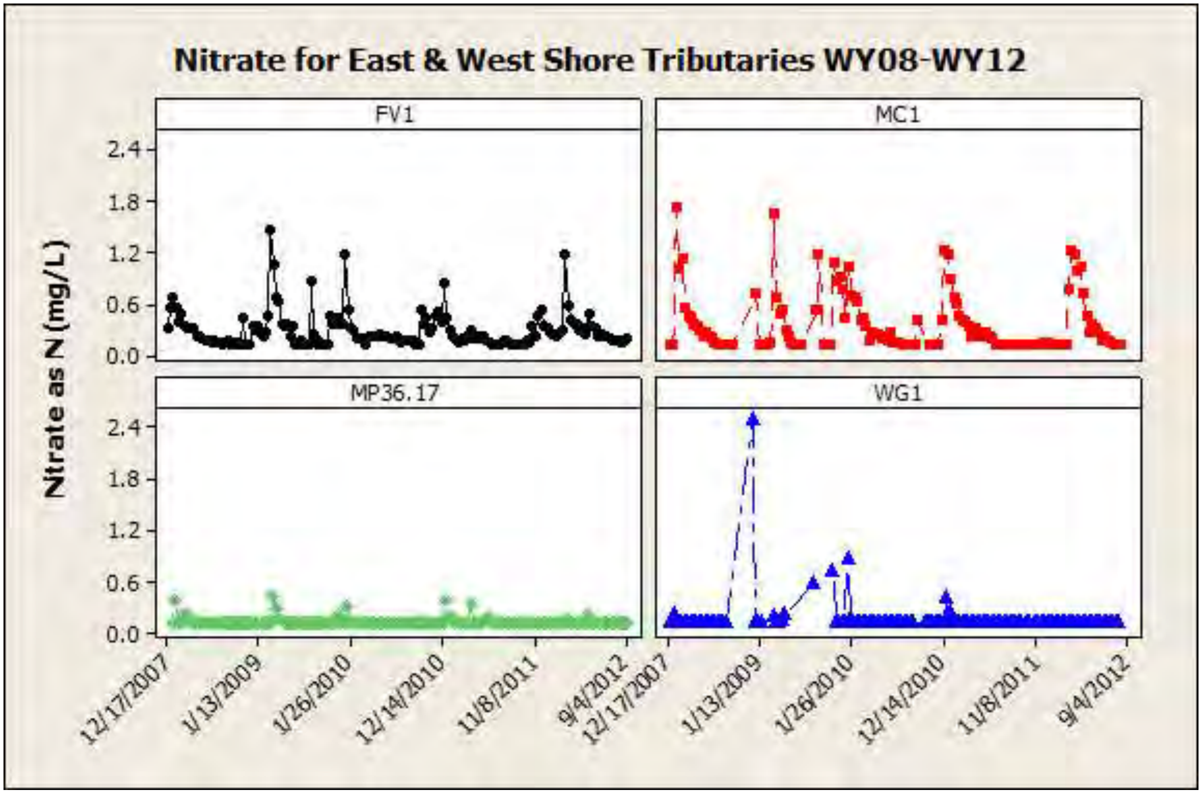
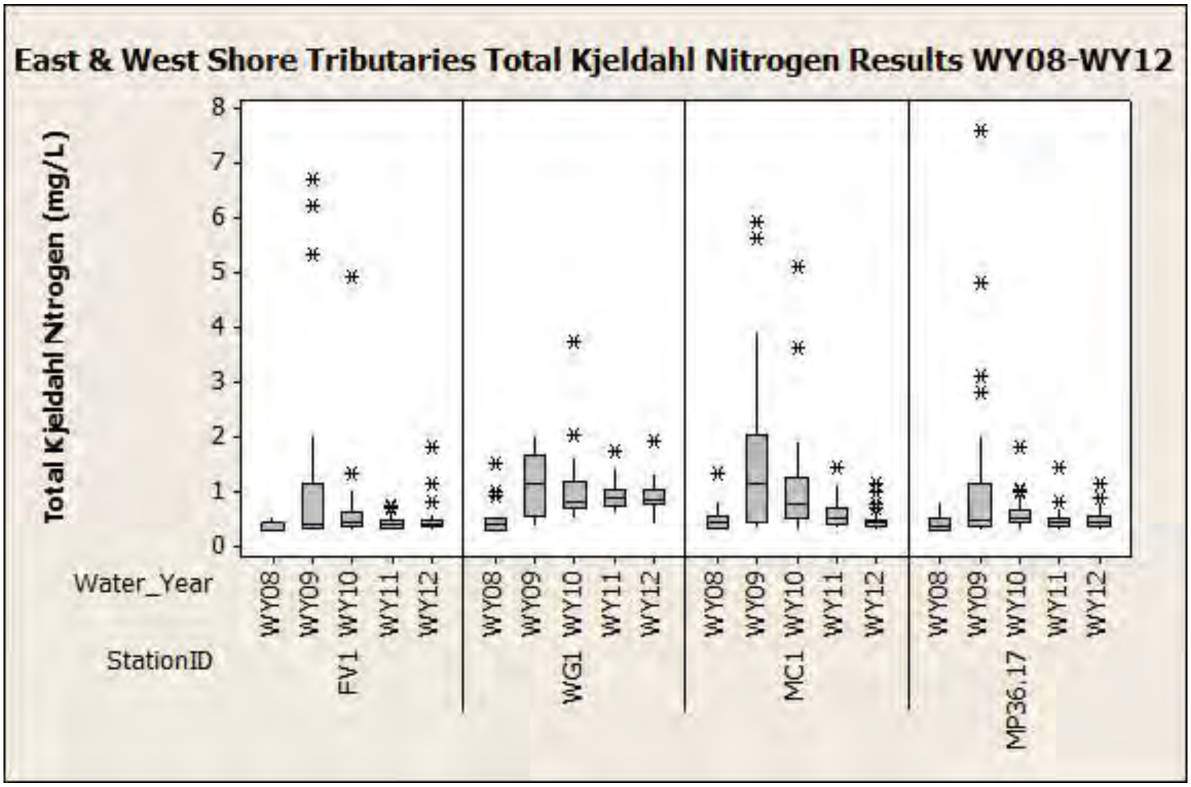


Figure 20 – East & West Shore Tributaries TKN by Water Year



Note: Above graph does not include 2 outliers, see graph in appendix D for complete results.

Figure 21– East & West Shore Tributaries TKN Time Series WY08-WY12

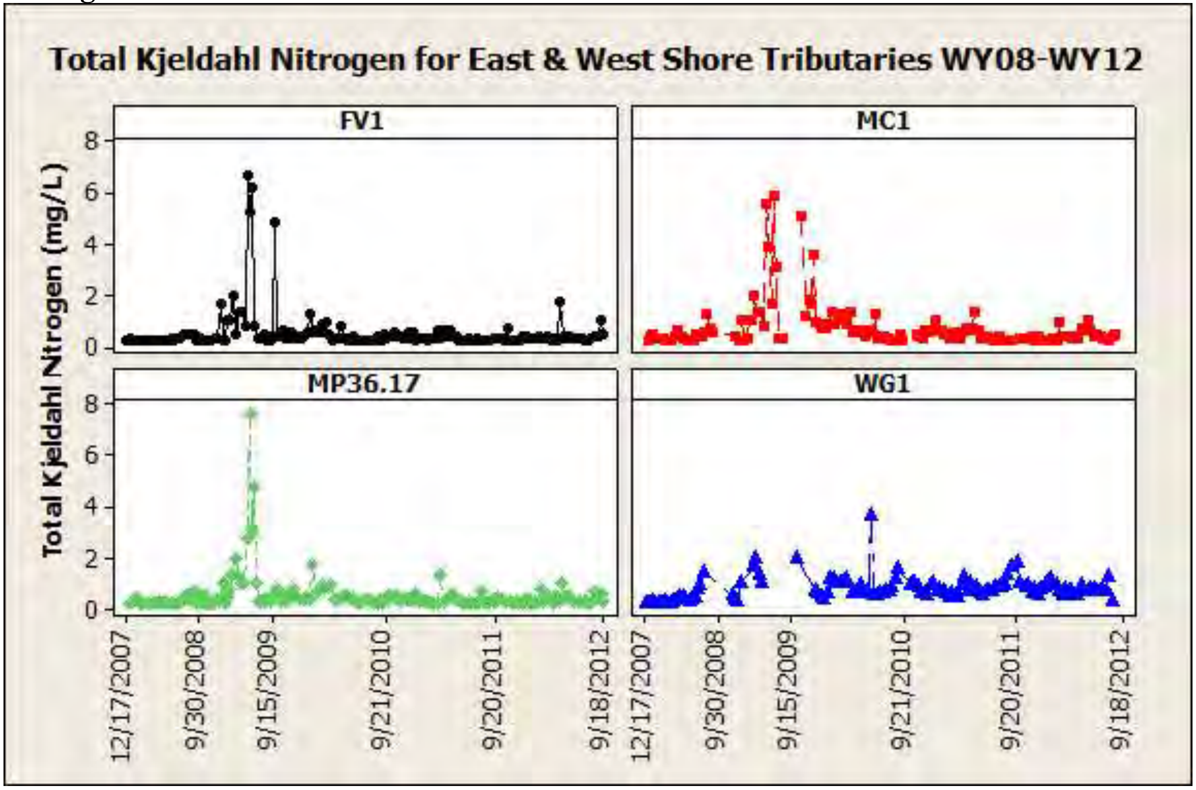


Figure 21 Note: Omitted values from: MC1 10/20/09 39.0 mg/L & WG1 3/24/09 of 15.0 mg/L; See Appendix D for timeseries plot of TKN including omitted extreme values.

Nutrient results from east and west-shore tributaries suggest persistent loading sources in several coastal creeks, with occasional, but severe, spikes during storm events. The magnitude of occasional spikes of nutrient parameters, particularly those from Millerton Gulch (MC1), suggests serious nutrient sources are connected to the larger watershed during periodic events, and that the local water quality conditions in some coastal streams has a direct negative impact on aquatic life in these areas (Peak result from MC1 in WY09 of more than 10 mg/L ammonia (NH_3 as N) represents toxic conditions for local aquatic species). It should be noted that discharge, or flow rates, are much lower in the east and west-shore coastal tributaries than those of most sites in the larger Lagunitas and Walker Creek watersheds, resulting in lower loading rates to Tomales Bay for these streams, even during severe runoff events. Like most streams in the watershed, elevated levels of both nitrate and TKN are associated with storm-related runoff events. Results of TKN analysis show that some sites have severe spikes (MC1 = 39 mg/L and WG1 = 15.0 mg/L) which demonstrate significant episodic loading of organic nitrogen and/or ammonia.

Figure 22 – Walker Creek Watershed Sites Nitrate Results by Water Year

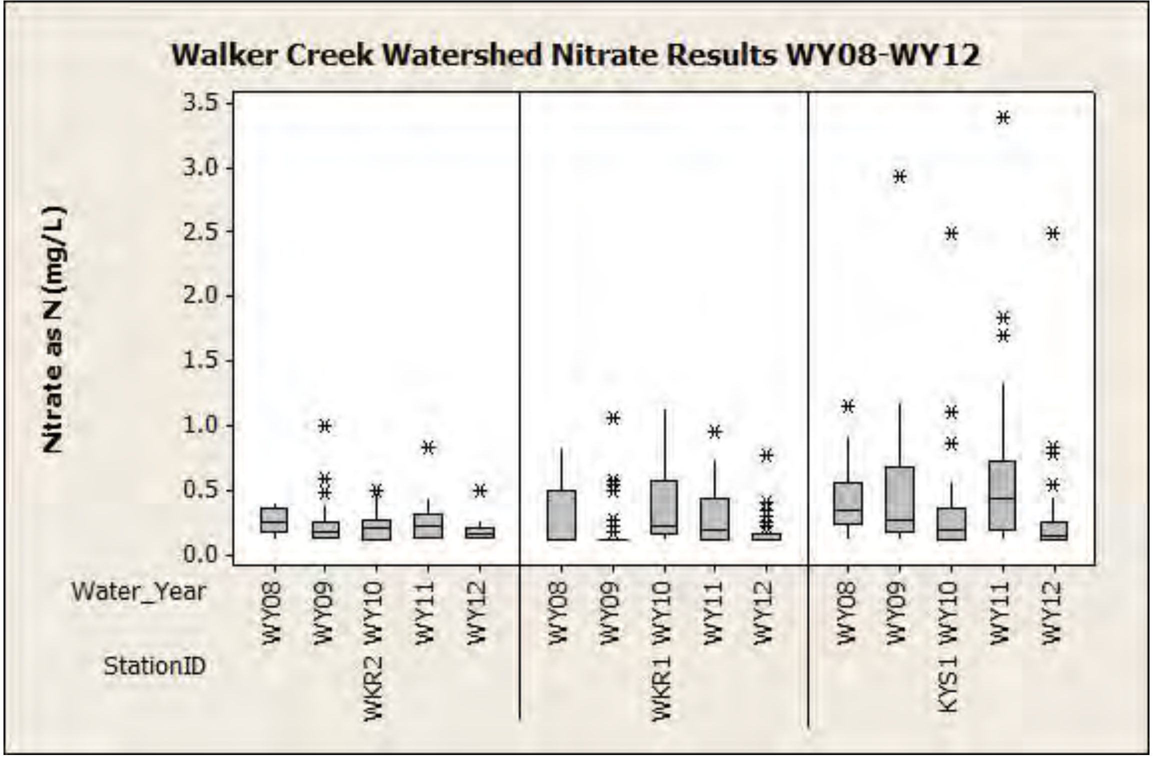


Figure 20 – Walker Creek Watershed Nitrate (NO_3) Time Series WY08-WY12

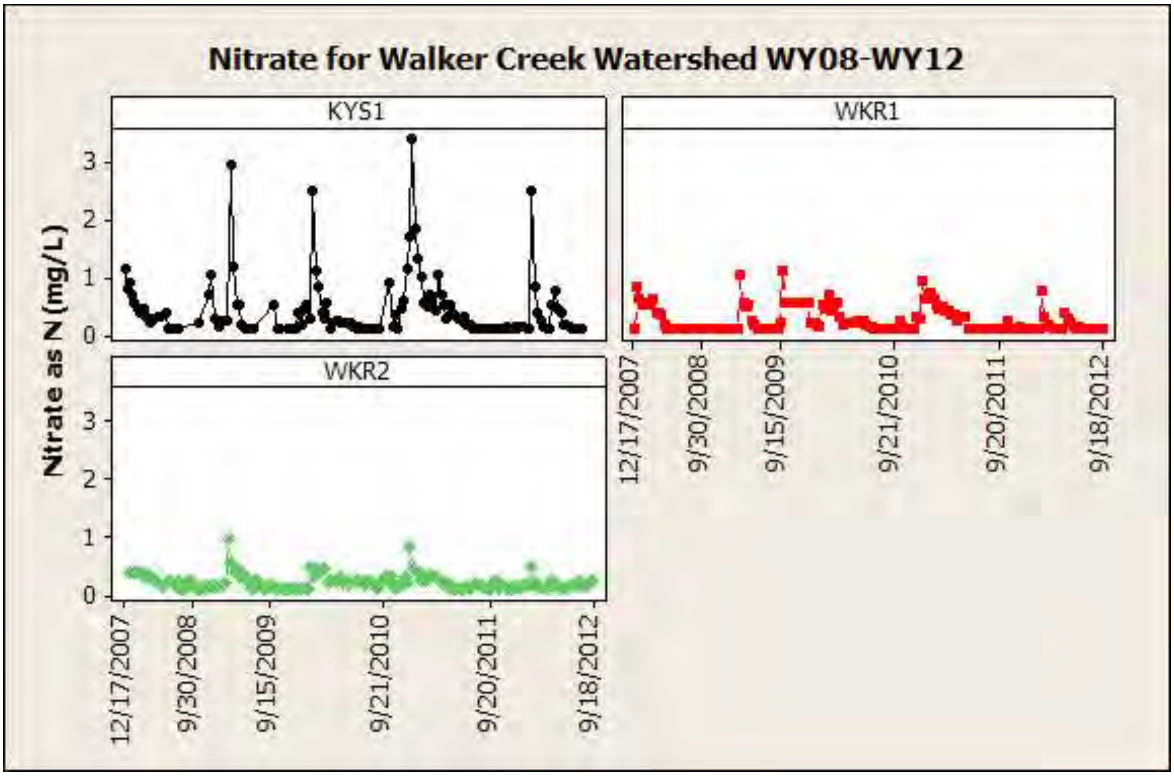


Figure 24 – Walker Creek Watershed Sites TKN Results by Water Year

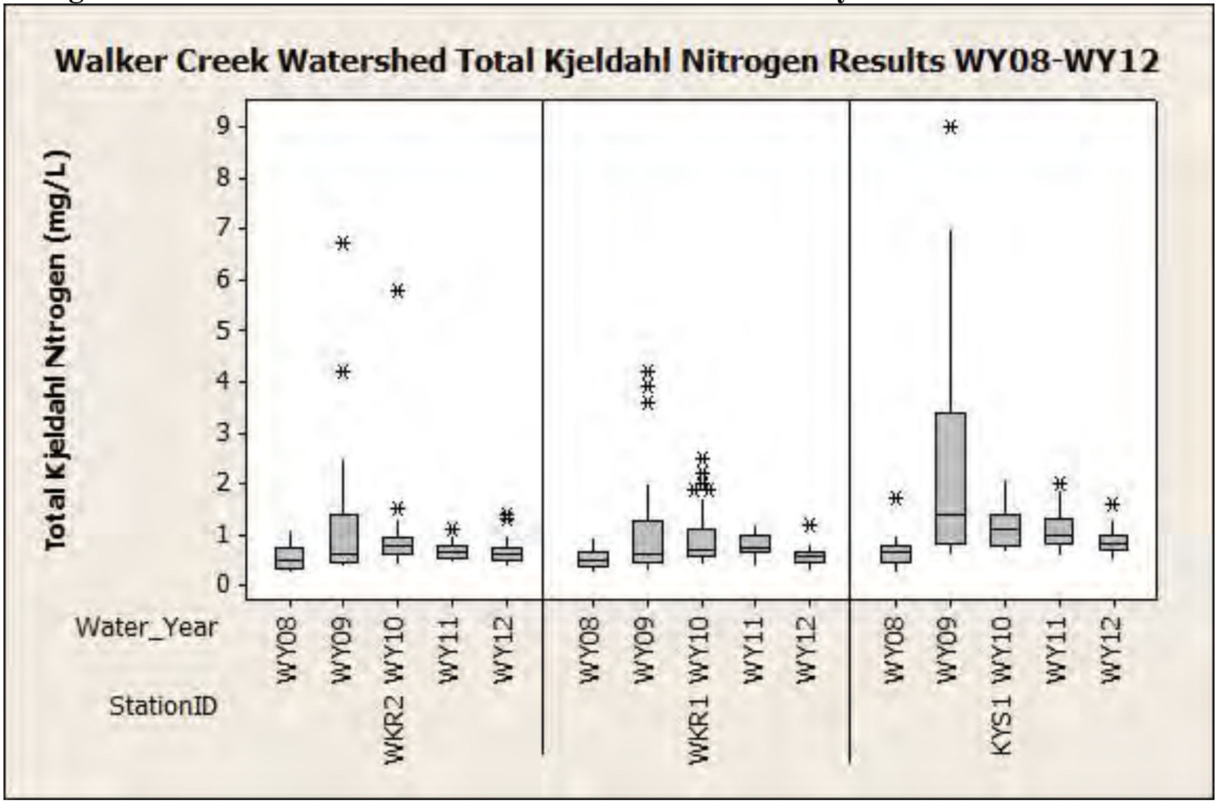
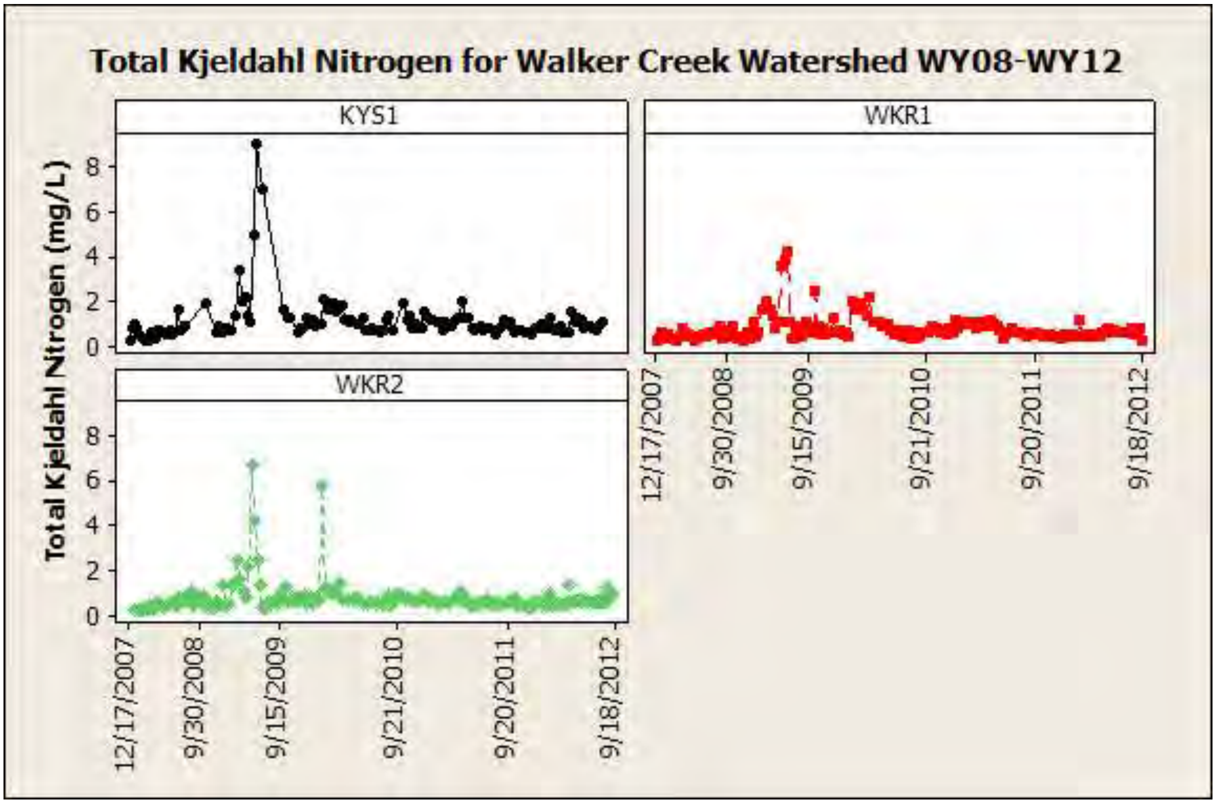


Figure 25 – Walker Creek Watershed TKN Time Series WY08-WY12



Results of nutrient analysis of sites in the Walker Creek watershed suggest that the watershed is a source of significant nutrient input to Tomales Bay, particularly during storm events. Peak input levels for nitrate and TKN are similar to sites in other sub-watersheds in the area, although concentrations during peak events tended to be higher at the Keys Creek (KYS1) and upper Walker Creek site (WKR2), with lower levels at the lower Walker Creek site, indicating some dilution from the lower watershed, or from tidal influx. Again, as noted for other sub-watersheds, the peak nutrient concentrations were associated with storm events. The highest levels of both nitrate (NO_3 as N) and TKN were observed at the site near the bottom of the Keys Creek watershed. It should be noted that discharge, or flow rates, from Keys Creek are much lower than those of most sites in the larger Lagunitas and mainstem Walker Creek watersheds, resulting in lower loading rates to Tomales Bay even during severe runoff events.

Figure 26 – Tomales Bay Sites Nitrate Results by Water Year

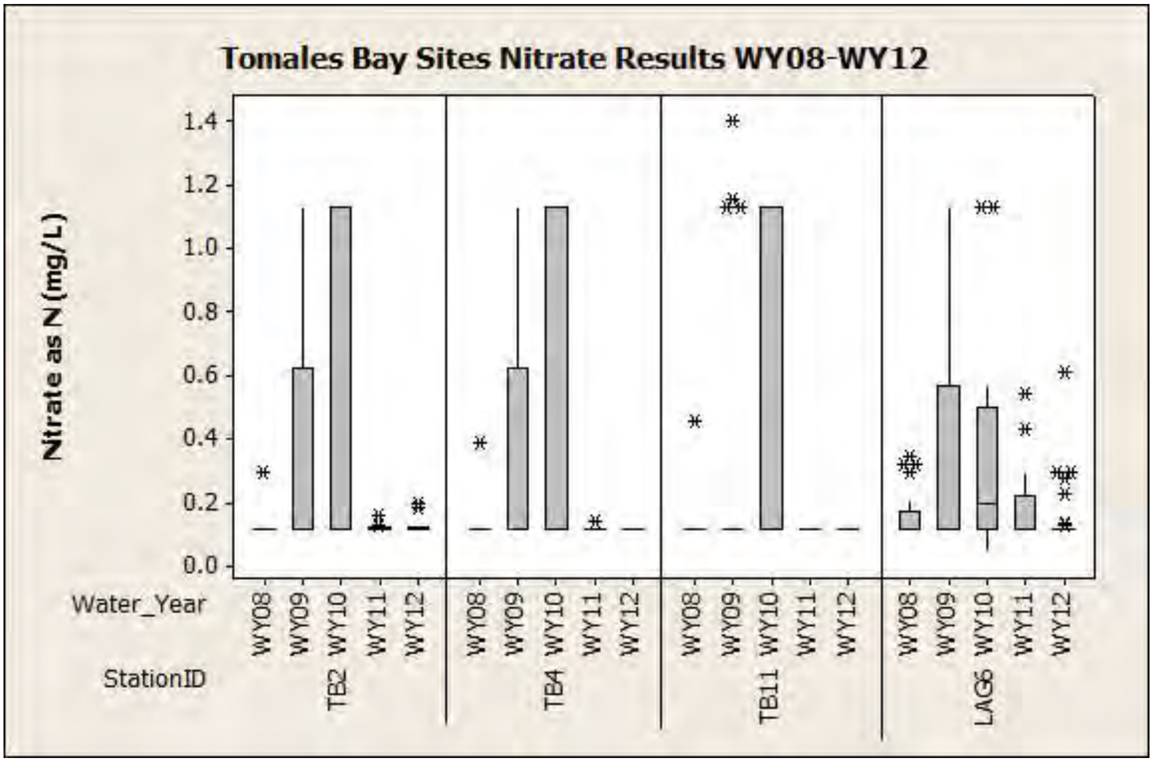


Figure 27 – Tomales Bay Sites Nitrate (NO_3) Time Series WY08-WY12

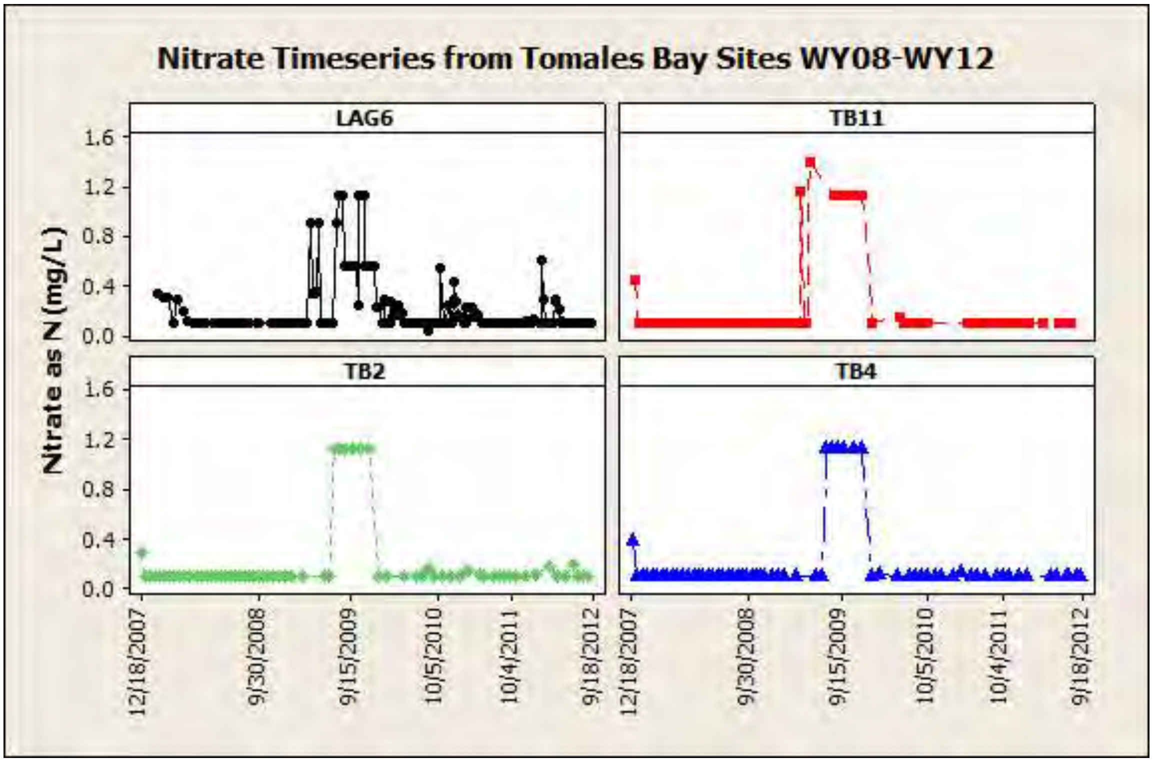


Figure 28 – Tomales Bay Sites TKN Results by Water Year

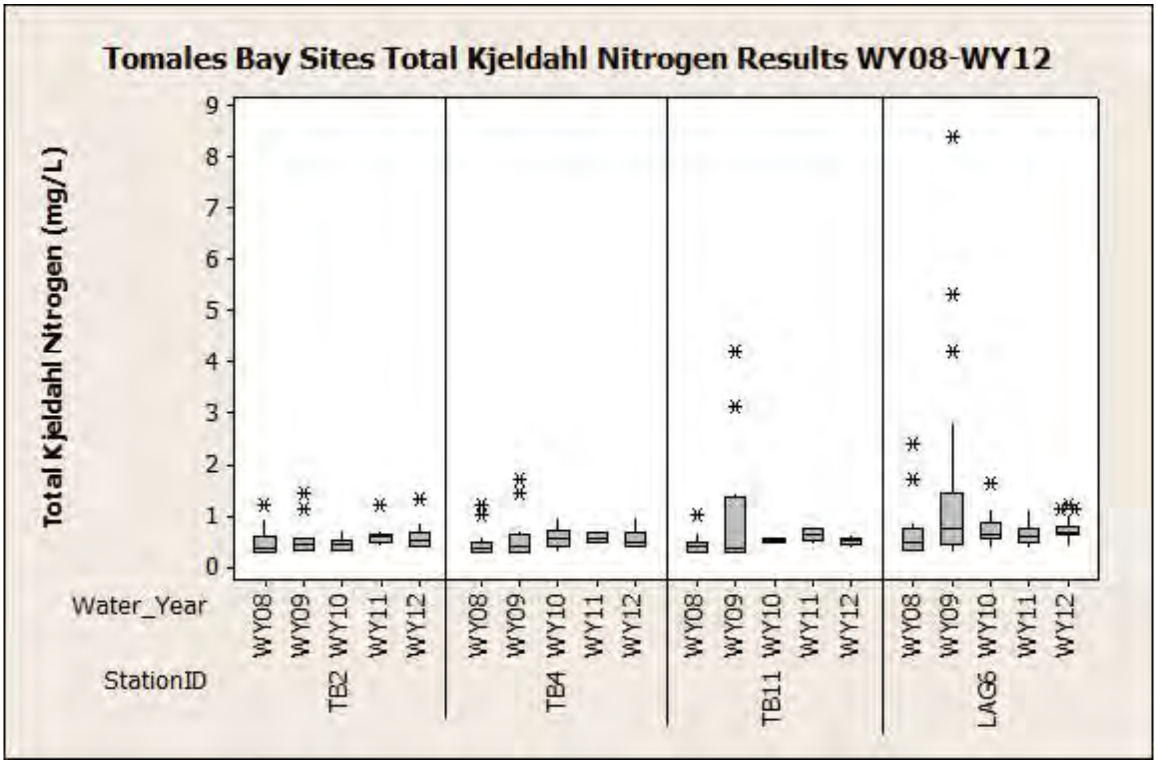
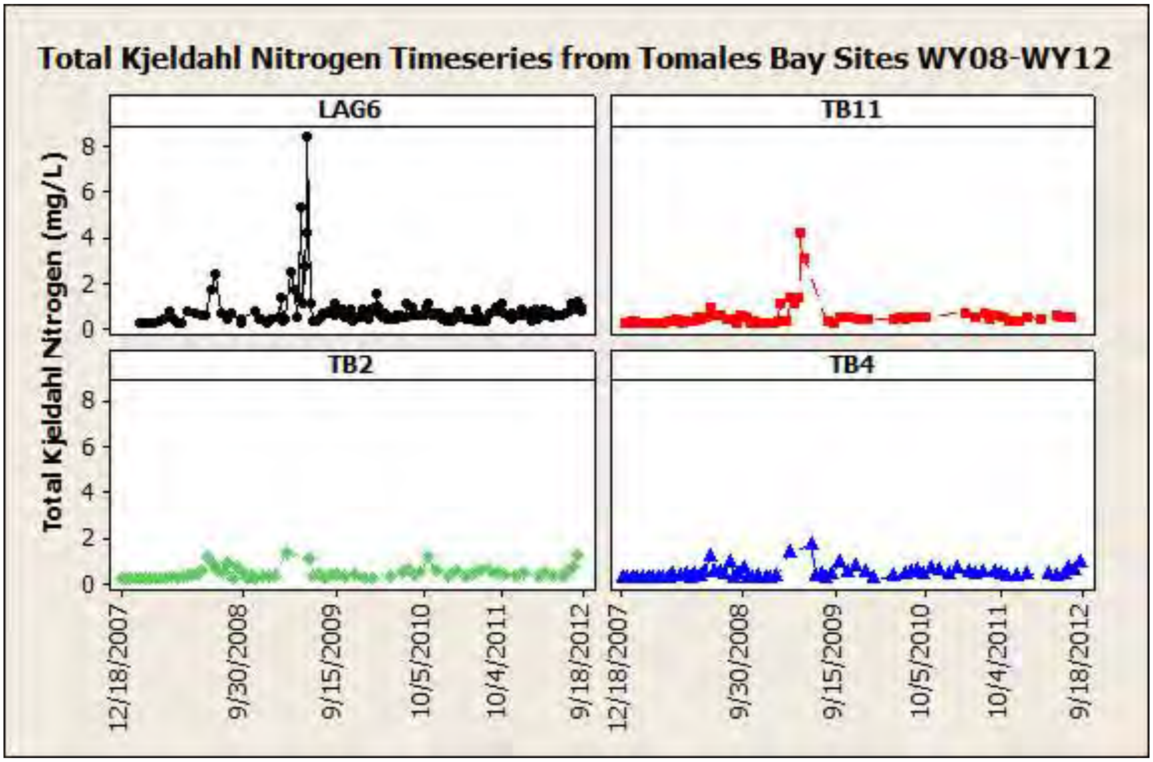


Figure 29 – Tomales Bay Sites TKN Time Series WY08-WY12



Analysis of nutrient results from sites along the length of Tomales Bay suggests that inner-Bay sites (LAG6 and TB11) are more strongly affected by nutrient inputs from tributary sites in the area. Results from the mid- and outer-Bay sites (TB4 and TB2 respectively) show very low levels of both nitrate and TKN during the sampling period. It should be noted again that samples from Bay sites were not taken during storm events in WY09, WY10, WY11 or WY12, making a true assessment of storm-related conditions at Bay sites impossible with this program data. The elevated levels seen in the time-series graphs of nitrate during late 2008-May 2009 is an artifact of a higher reporting limit due to site salinity from a different contract lab during this period, it does not necessarily reflect actual nutrient levels. It should be noted that LAG6 site is in Lagunitas Creek, upstream of Tomales Bay itself, and it thus more directly influenced by conditions in the Lagunitas Creek watershed than those in the Bay. The inner-Bay site (TB11) is near Millerton Point, and is heavily influenced by input from Millerton Gulch, which has demonstrated episodically high levels of nutrient input during storm events.

Results of Sediment Trends Monitoring for WY08-WY12

Elevated levels of sediment, measured through turbidity or total suspended solids can have detrimental effects on aquatic organisms indirectly through increased difficulty locating food, and directly by clogging organisms’ gills, or by smothering developing eggs in the stream substrate. In coastal streams, high levels of sediment are common in winter during high water flow. This is a natural result of the dry climate and low-frequency, high intensity storms. The dry climate leaves large areas of the watershed covered only by dry grass that provides little protection from erosion. The interpretation of high sediment levels as pollution, or as a natural event depends largely on the circumstances. Conventional pollution, such as bacteria, some nutrients and metals are often attached to sediment particles that are mobilized during runoff. So, high sediment levels often mean increased levels of these other conventional pollutants.

Lagunitas and Walker Creeks, as well as Tomales Bay are listed as impaired by sediment. The Trends program monitored levels of turbidity as well as total suspended solids (TSS) during the first year of monitoring. Total suspended solids is a time-consuming and expensive test, and it was determined that the more general measurement of turbidity was sufficient to document the relative level of sediment pollution in this watershed, with occasional TSS samples collected during storm events to build on correlations with existing data.

The RWQCB has begun the process of planning for the sediment TMDL for impairments in this watershed, and data generated by this program as well as results we have compiled from other studies should help inform the TMDL development process.

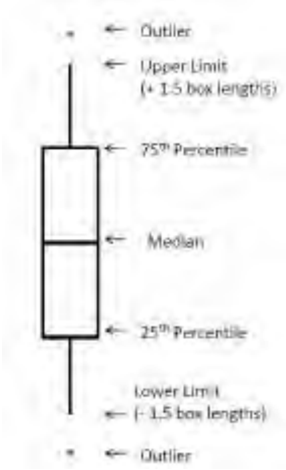
Turbidity – is a measure of the clarity of a water sample. It is a proxy for the amount of suspended solids in a water sample and is determined by measuring the light transmission or visibility through a disturbed sample. Turbidity is reported in nephelometric turbidity units (NTU). A correlation between turbidity and total suspended solids (TSS) can be developed for a stream, making quantification of sediment pollution easier. RWQCB's Basin Plan (RWQCB 2007) does not establish numeric criteria for turbidity, but states the following: "Waters shall be free of changes in turbidity that cause nuisance or adversely affect beneficial uses". The EPA guidance to states on numeric water quality objectives provides recommended turbidity criteria for aggregate ecoregion III rivers and streams of 2.34 NTU.

Total Suspended Solids (TSS) – is a measure of the total weight of solids suspended in a water sample. A water sample is filtered, and the dry weight of the filtrand (or residue on the filter) is totaled to determine TSS in mg/L. Both turbidity and TSS are measures of the sediment or other suspended materials in surface water. Elevated sediment levels can impact aquatic life in two ways: Extremely high levels can clog fish gills, or cover gravel spawning beds, suffocating both fish and eggs; Long-lasting turbidity can affect the ability of aquatic organisms to feed. The RWQCB's Basin Plan (RWQCB 2010) does not establish numeric criteria for TSS, but states the following: "The suspended sediment load and suspended sediment discharge rate of surface waters shall not be altered in such a manner as to cause nuisance or adversely affect beneficial uses."

Table 4 – WY12 Sediment Parameter Results for Trends Monitoring by Station

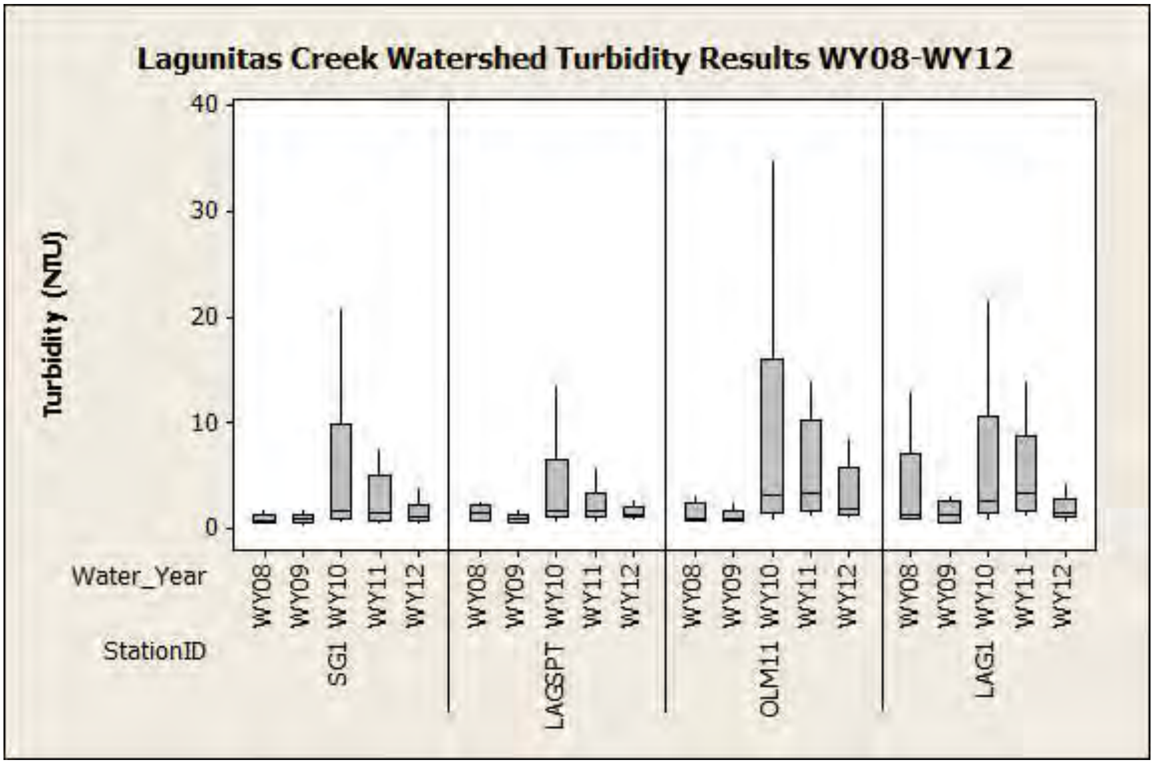
WY12 Sediment Lab Data						
	Turbidity (NTU)					
Site Name	# of detections	# samples <QL	Min.	Max.	Mean	Median
Lagunitas Creek						
SG1	38	0	0.30	107.00	5.86	1.00
LAGSPT	37	0	0.57	31.90	3.60	1.28
OLM11	38	0	0.77	122.00	8.33	1.66
LAG1	38	0	0.54	34.70	3.98	1.43
West Shore						
FV1	38	0	0.8	85	5.613	1.83
WG1	30	0	3.48	629	54.79	17.9
East Shore						
MC1	32	0	0.23	56.4	7.323	1.06
MP36.17	38	0	0.24	53.6	9.893	2.56
Walker Creek						
WKR2	38	0	0.77	107	9.583	3.12
WKR1	38	0	1.28	58.5	6.998	3.41
KYS1	31	0	3.49	50.7	11.04	6.97
Tomales Bay Sites						
TB2	11	0	2	3.98	2.862	2.83
TB4	10	0	0.9	5.2	2.332	1.96
TB11	8	0	0.7	9.88	4.266	-
LAG6	38	0	5.02	70.2	13.33	8.92

The following graphs show (boxplots) of the results of sediment monitoring (Turbidity) at Trends Program sites by site for each subwatershed grouping. A boxplot displays information about the range and distribution of data within the range (see figure at right). For the graphs in this report, the whiskers extending above and below the box are 1.5-times the middle 50% range box, with outliers shown by the asterisks (*). This treatment, which is a common variation on traditional boxplots whose whiskers extend to the minimum and maximum values, allows for the identification of outliers and extreme outliers that demonstrate the distribution and frequency of such results. To present the data in the most useful form, outliers are omitted from the box-plot graphs below, but are included in graphs in Appendix D of this document.



Also, see Appendix D for graphs of turbidity results for each site with each year graphed by water-year week to enable site-specific comparisons across water year.

Figure 30– Lagunitas Creek Watershed Sites Turbidity Results by Water Year



Note: Above graph does not include outliers, see graph in appendix D for complete results.

Figure 31– Lagunitas Creek Watershed Sites Turbidity Time Series WY08-WY12

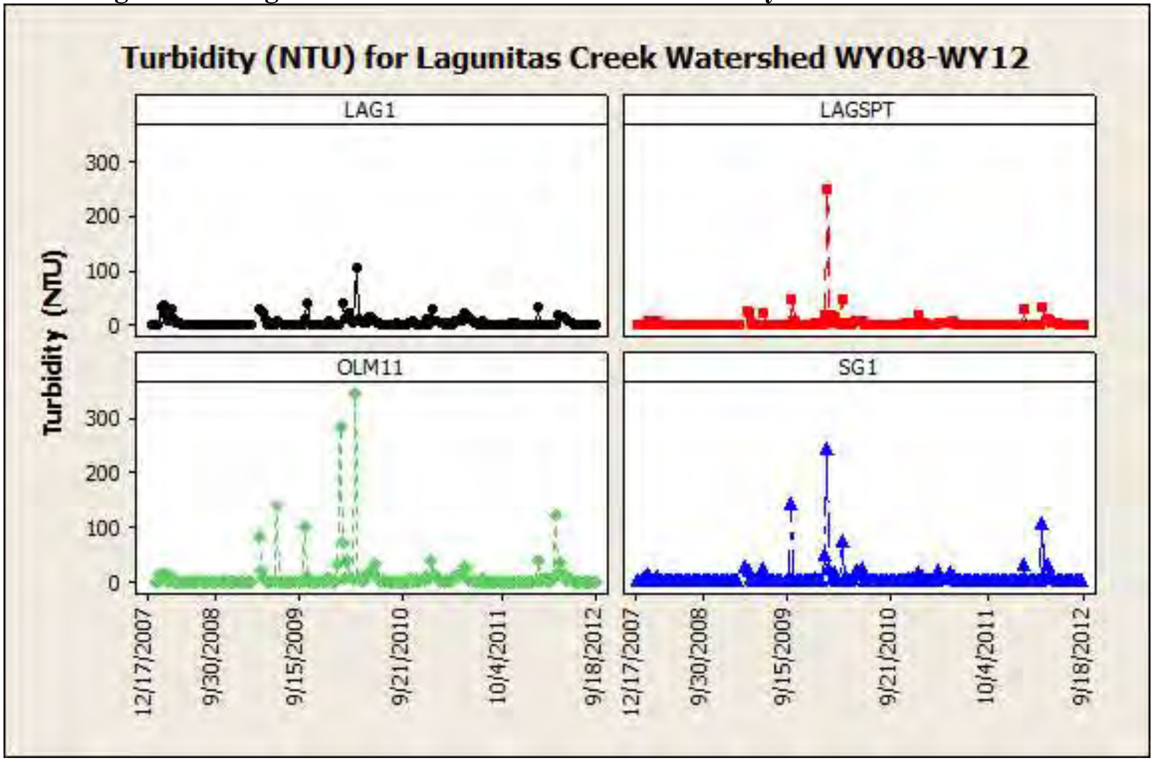
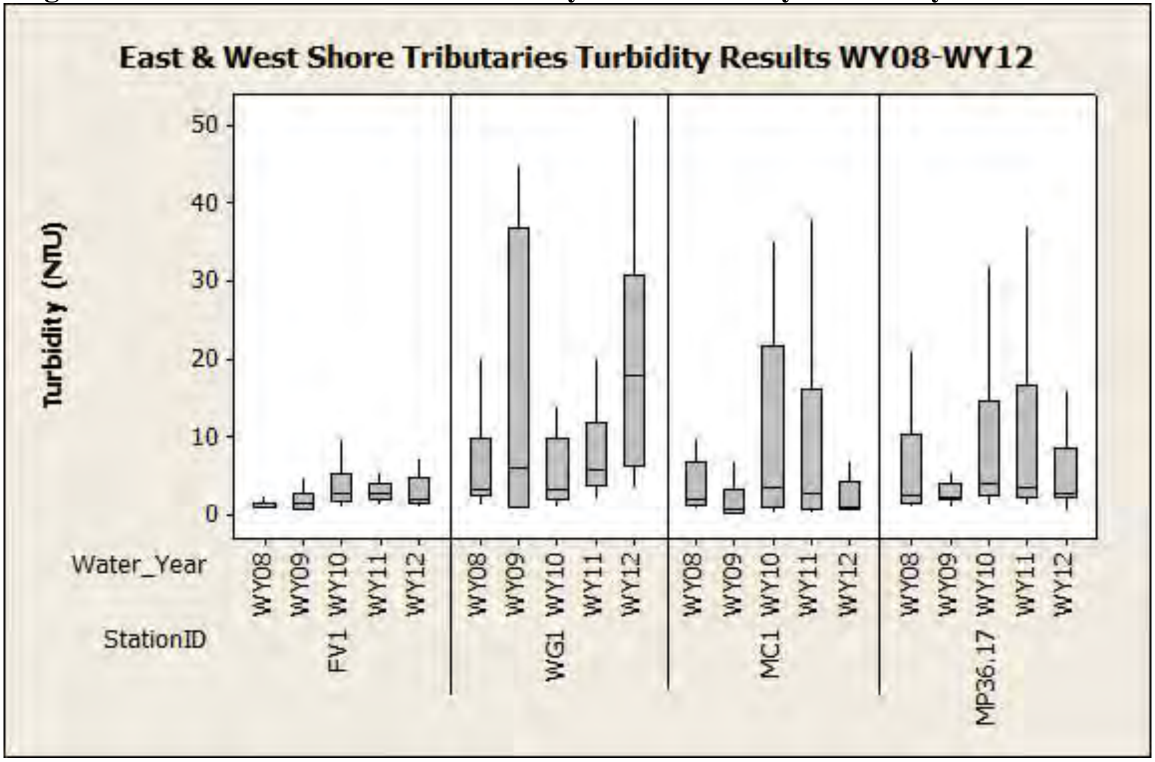


Figure 31 Note: One outlier result from LAG1 of 899.0 NTU from WY10 omitted from graph.

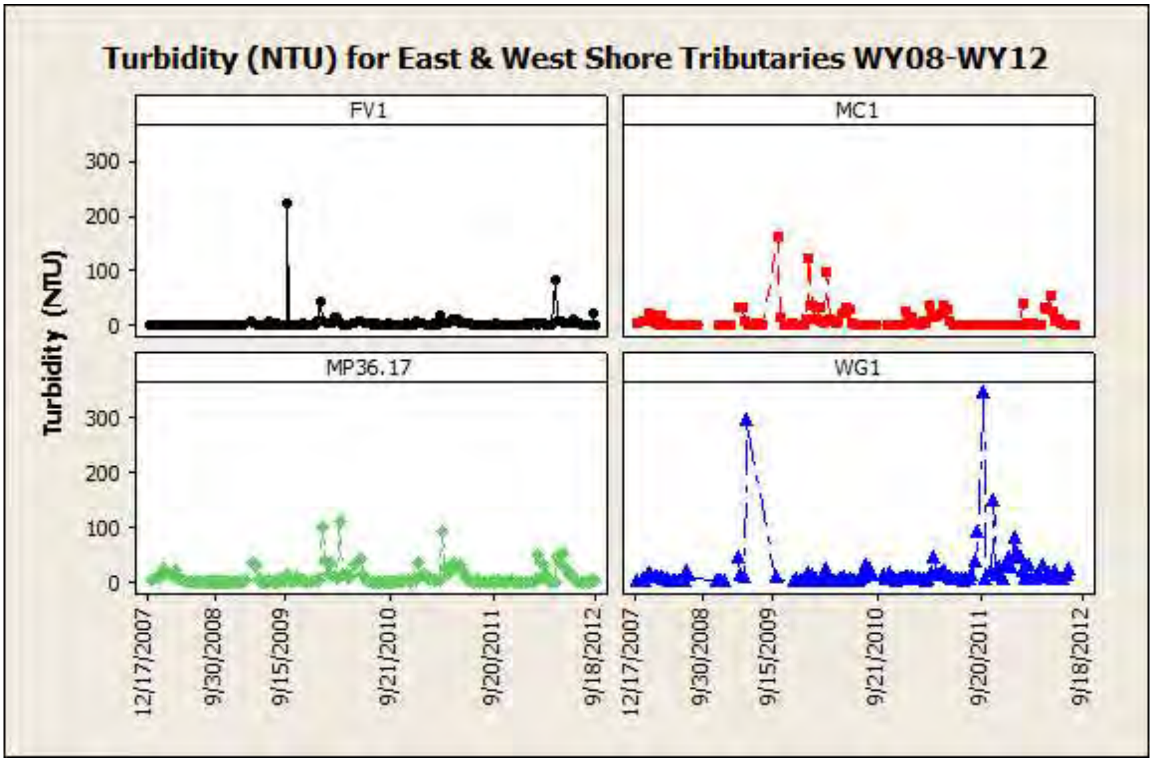
Analysis of turbidity results from the Lagunitas Creek watershed shows that most sites in the watershed show very high levels of sediment during storm events. Turbidity levels do appear to decline between the upper Lagunitas sites (SG1 and LAGSPT) and the lower Lagunitas Creek sites (LAG1 and LAG6) suggesting that some dilution or settling-out does occur in the lower watershed. Levels of sediment loading are heavily influenced by storm events, as can be seen by the increased frequency of elevated results during the 2010 and 2011 water years which had much more frequent storm events, and so, more storm samples represented in the dataset.

Figure 32 – East & West Shore Tributary Sites Turbidity Results by Water Year



Note: Above graph does not include outliers, see graph in appendix D for complete results.

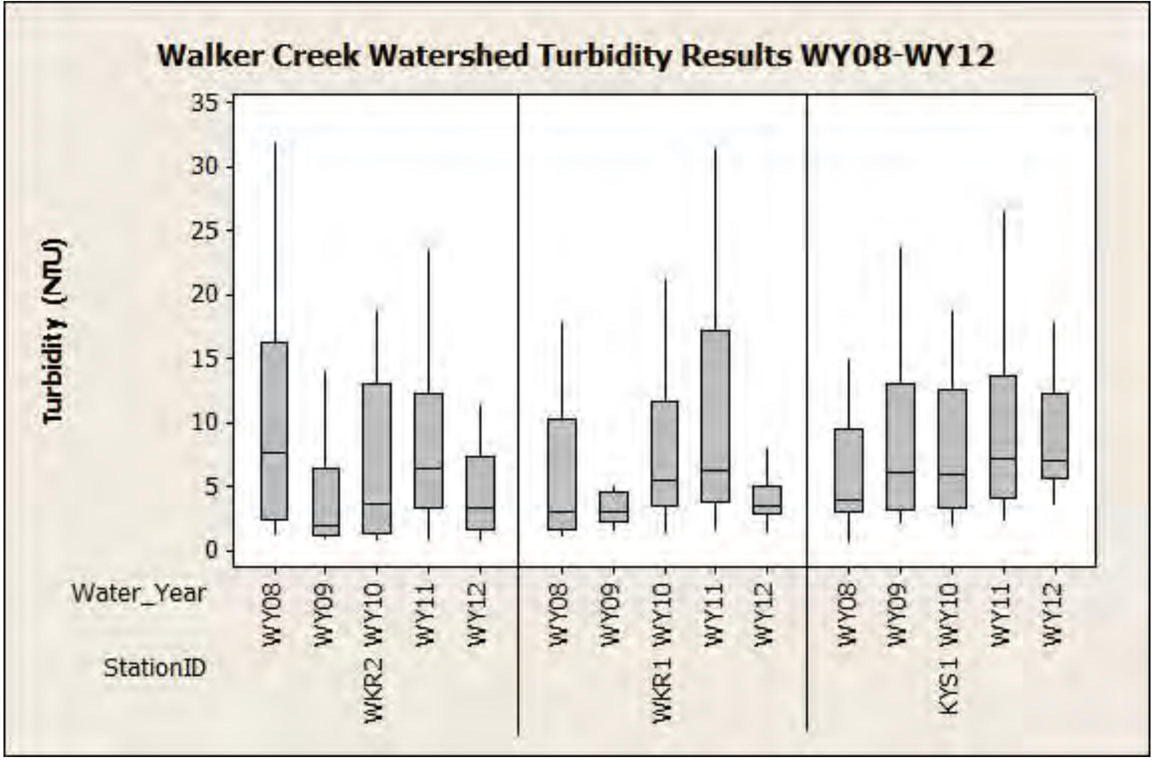
Figure 33 – East & West Shore Tributaries Turbidity Time Series by Water Year



Note: The above graph does not include one outlier, see Appendix D for complete series

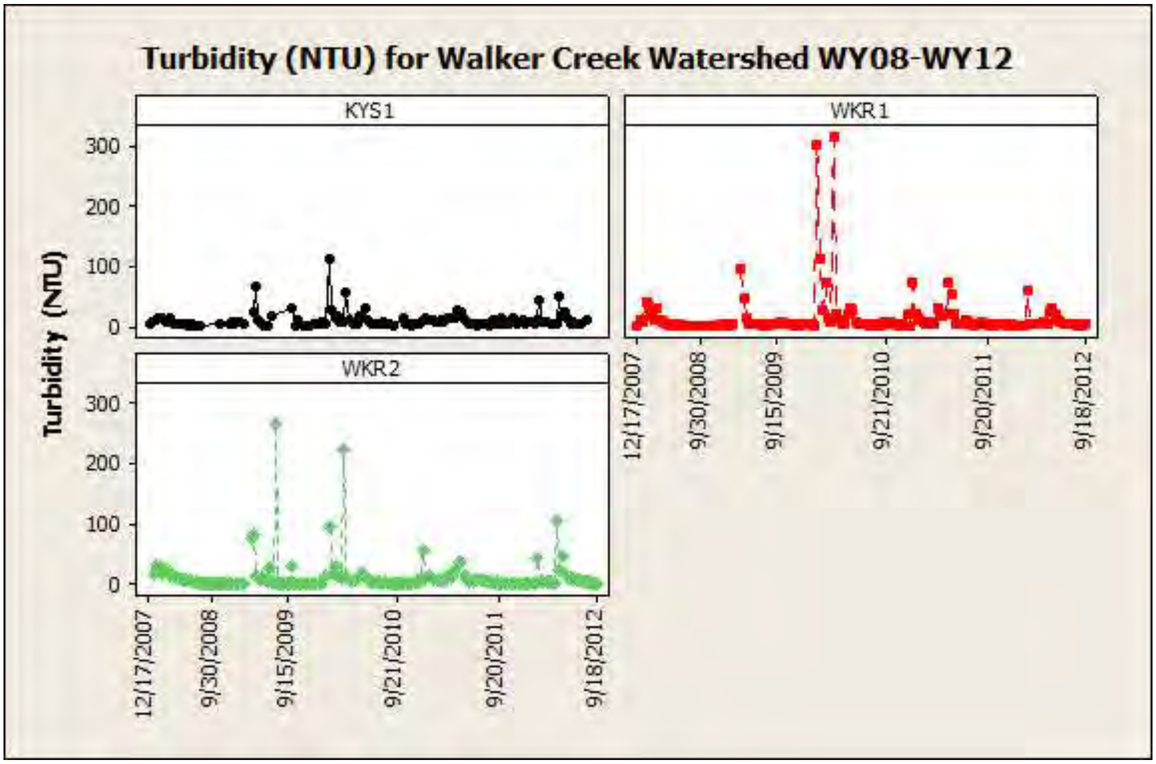
Analysis of turbidity results from the east- and west-shore watershed sites shows that levels are relatively low at all sites during most of the year, with occasional spikes during significant storm events. Again, discharge rates from coastal tributaries are a fraction of that from most other sites in the watershed, and so, loading rates of sediment at a given concentration from these tributaries are lower than those from most other sites in the Tomales Bay watershed.

Figure 34 – Walker Creek Watershed Sites Turbidity Results by Water Year



Note: Above graph does <u>not</u> include outliers, see graph in appendix D for complete results.

Figure 35 – Walker Creek Sites Turbidity Time Series WY08-WY12



Note: One outlier result from WKR2 of 1000.0 NTU from WY10 omitted from graph.

Analysis of turbidity results from the Walker Creek watershed shows that some sites in the watershed show very high levels of sediment during storm events. Turbidity levels do not appear to decline between the upper Walker Creek site (WKR2) and the lower Walker Creek site (WKR1) suggesting that loading is occurring throughout the watershed. Levels of sediment loading are heavily influenced by storm events, as can be seen by the increased frequency of extreme results during the 2010 water year which had much more frequent storm events, and so, more storm samples represented in the dataset.

Figure 36 – Tomales Bay Sites Turbidity Results by Water Year

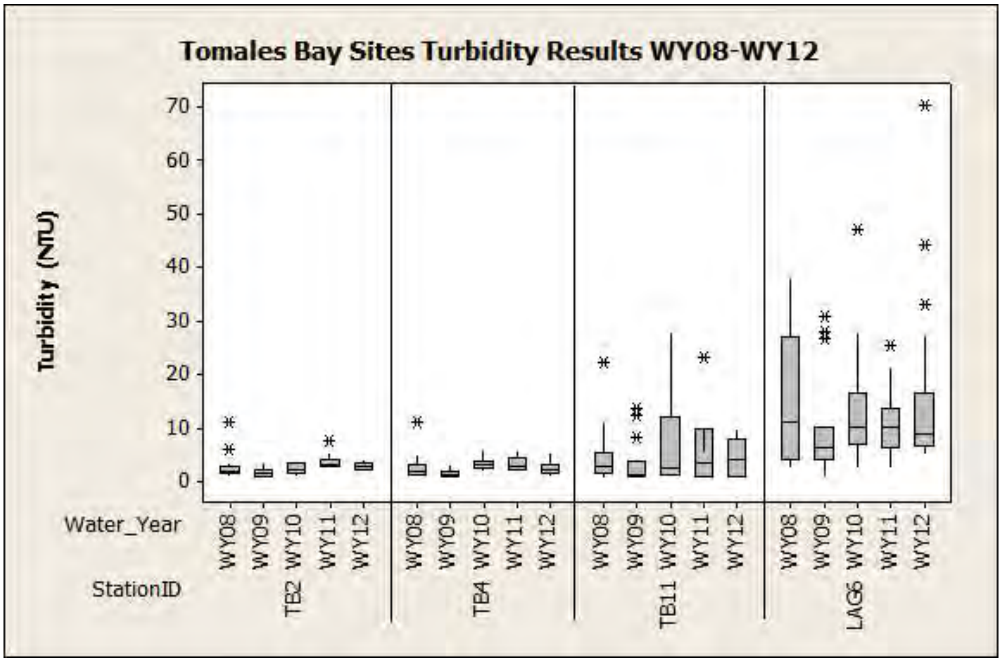
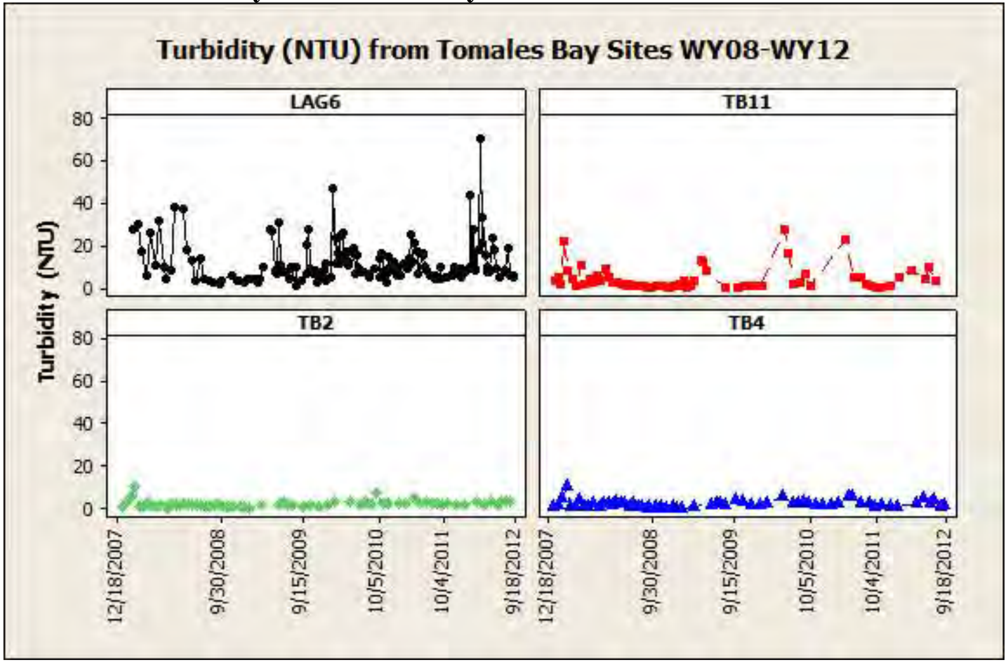


Figure 37 – Tomales Bay Sites Turbidity Time Series WY08-WY12



Analysis of turbidity results from sites along the length of Tomales Bay shows that most sites in the watershed show relatively low levels of sediment, although it should be noted again that samples from Bay sites were not taken during storm events in WY09, WY10 and WY11 making a true assessment of storm-related conditions at Bay sites impossible. Turbidity levels do appear to decline between the upper Lagunitas sites (SG1, LAGSPT and LAG1) and the lowest Lagunitas Creek site (LAG6) suggesting that some dilution, settling or filtration does occur in the wetland and lower watershed.

Bacteria Monitoring Results for Trends Program WY08-WY12

Bacteria monitoring is an essential element of the Trends program. Because Lagunitas and Walker Creeks as well as Tomales Bay are listed as impaired for pathogens, significant efforts by regulatory authorities, land-owners and citizen groups have been made to understand the nature of the problem. The RWQCB has a pathogen TMDL implementation plan for the watershed, and various state and federal agencies have been conducting studies of bacteria in the watershed including the U.S. EPA (Smith, et al., 1971) and the California Dept. of Health Services (Sharpe, 1974). For more information on past studies, see the Data Management and Legacy Datasets section of this report.

The levels of certain bacteria groups are used as a proxy for the likelihood of the presence of disease-causing bacteria (pathogens) for which there are no reliable direct tests. This watershed is characterized by large winter rain events which trigger significant surface runoff, and saturate soils connecting sub-surface sources with the streams. This results in relatively low levels of detected bacteria during the dry season, with exponentially-higher levels resulting from rain events during the winter. This pattern makes it difficult, or maybe impossible to meet year-round compliance with strict numeric targets. This program seeks to document long-term trends, including the location, timing, magnitude and duration of bacteria loading throughout the watershed.

Bacteria – Certain types of bacteria (like coliform bacteria) are used as indicators of pathogen contamination in water samples. The coliform bacteria are ubiquitous in the environment, even growing in soils. Fecal coliform bacteria grow only in the intestinal tracts of warm-blooded animals. While most coliform are harmless, the levels of Total Coliform (TC) and Fecal Coliform (FC) (a subset of TC) are used as an indicator for the potential presence of other pathogenic, disease-causing bacteria and viruses. Samples are analyzed by culturing any TC/FC bacteria present, counting the number of colonies, and using statistical models to generate a Most Probable Number (MPN) of bacteria present in 100mL of sample water. Because it is an indirect measure of potential threat to human health, fecal coliform bacteria is widely-acknowledged to be an inadequate method for identifying levels of pathogens in water. While new methods of determining source organisms and direct pathogen detection are emerging, they remain inconsistent and prohibitively expensive at present.

The RWQCB's Basin Plan (RWQCB 2010) established numeric objectives for total and fecal coliform bacteria in surface waters based on three beneficial uses: Contact Recreation, Non-Contact Recreation and Shellfish Harvesting. (see table 1 for numeric targets below).

Table 5 – Beneficial Uses Coliform Bacteria Criteria (RWQCB, 2010)

Beneficial Use	Total Coliform (TC)	Fecal Coliform (FC)
Contact Recreation	Median: < 240 MPN/100mL No sample > 10,000 MPN/100mL	Log mean < 200 MPN/100mL* 90th Percentile < 400 MPN/100mL
Non-Contact Recreation		Log mean < 2,000 MPN/100mL 90th percentile < 4,000 MPN/100mL
Shellfish Harvesting	Median < 70MPN/100mL 90th percentile < 230 MPN/100mL	Median < 14 MPN/100mL 90th percentile < 43 MPN/100mL

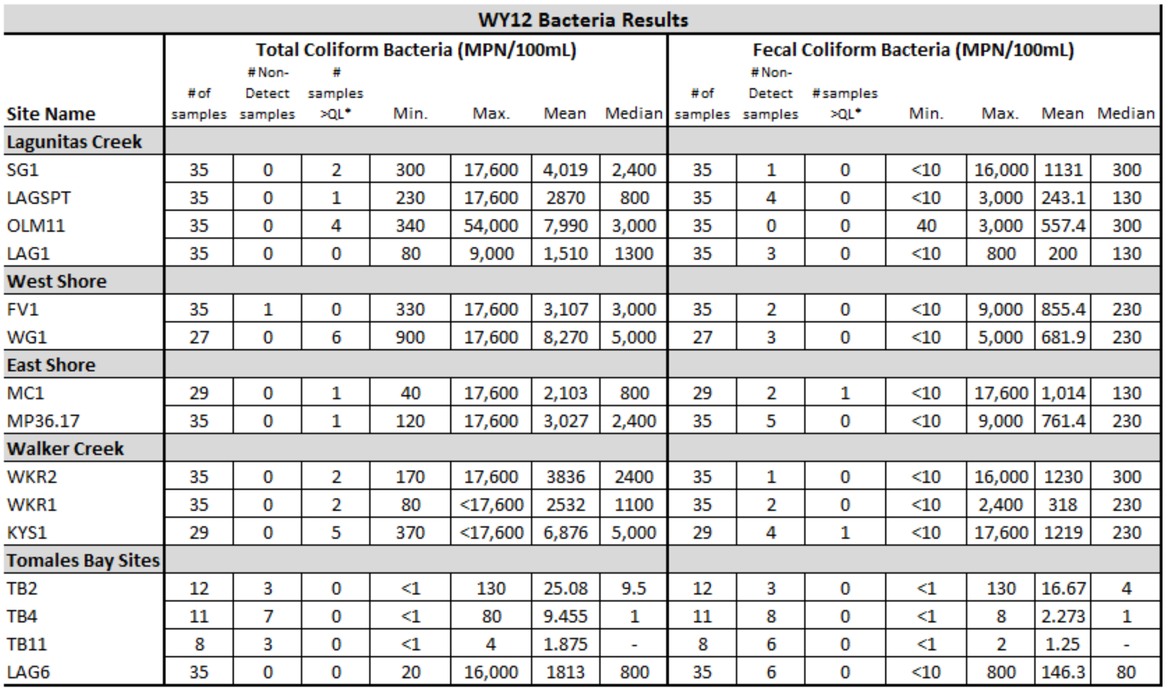
*Based on five consecutive samples equally-spaced in time.

Table 6 below shows summary statistics by site for bacteria data (Total Coliform and Fecal Coliform) collected by the Trends Program during WY12. Following this are summaries by major sub-watershed for the same data. For the purposes of comparison, only the fecal coliform data is included in the sub-watershed analysis. During the state funding freeze in 2008-2009, no samples were analyzed for total coliform bacteria.

Trends Program data are compared to the single-sample contact recreation standard (90th percentile <400 MPN/10mL) for tributary sites (including LAG6), and to the shellfish harvesting standard (90th percentile <43 MPN/100mL) for Bay sites (TB2, TB4, TB11). This standard means that no more than 10% of samples from a site for a given time period may exceed the appropriate standard. No tributary sites met this standard for the period of record. A detailed summary of each watershed and site is provided in the following section. The secondary standards for contact recreation and shellfish harvesting uses the geometric or log mean of a minimum of five consecutive samples equally spaced over a 30-day period. Fecal coliform results from each site are presented, along with the calculated geometric mean compared to the appropriate standard. Graphs of geometric means for each site are calculated using the previous five samples, which are weekly during the wet season, and twice monthly during the dry season. Normally, geometric means are calculated from 5 samples in a 30-day period. While the dry-season data treatment is a slightly unconventional in using 5 samples spanning more than 2 months, it does provide a useful visual depiction of data distribution and relation to the appropriate water quality criteria.

See Appendix D for graphs of fecal coliform bacteria results for each site with each year graphed by water-year week to enable site-specific comparisons across water year.

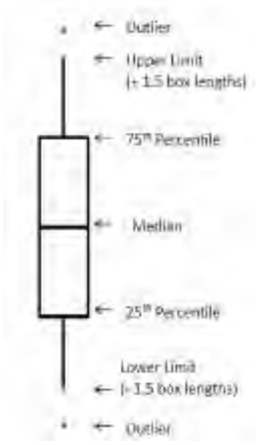
Table 6 – WY12 Bacteria Parameter Results for Trends Monitoring by Station



WY12 Bacteria Results

	Total Coliform Bacteria (MPN/100mL)							Fecal Coliform Bacteria (MPN/100mL)						
Site Name	# of samples	# Non-Detect samples	# samples >QL*	Min.	Max.	Mean	Median	# of samples	# Non-Detect samples	# samples >QL*	Min.	Max.	Mean	Median
Lagunitas Creek														
SG1	35	0	2	300	17,600	4,019	2,400	35	1	0	<10	16,000	1131	300
LAGSPT	35	0	1	230	17,600	2870	800	35	4	0	<10	3,000	243.1	130
OLM11	35	0	4	340	54,000	7,990	3,000	35	0	0	40	3,000	557.4	300
LAG1	35	0	0	80	9,000	1,510	1300	35	3	0	<10	800	200	130
West Shore														
FV1	35	1	0	330	17,600	3,107	3,000	35	2	0	<10	9,000	855.4	230
WG1	27	0	6	900	17,600	8,270	5,000	27	3	0	<10	5,000	681.9	230
East Shore														
MC1	29	0	1	40	17,600	2,103	800	29	2	1	<10	17,600	1,014	130
MP36.17	35	0	1	120	17,600	3,027	2,400	35	5	0	<10	9,000	761.4	230
Walker Creek														
WKR2	35	0	2	170	17,600	3836	2400	35	1	0	<10	16,000	1230	300
WKR1	35	0	2	80	<17,600	2532	1100	35	2	0	<10	2,400	318	230
KYS1	29	0	5	370	<17,600	6,876	5,000	29	4	1	<10	17,600	1219	230
Tomales Bay Sites														
TB2	12	3	0	<1	130	25.08	9.5	12	3	0	<1	130	16.67	4
TB4	11	7	0	<1	80	9.455	1	11	8	0	<1	8	2.273	1
TB11	8	3	0	<1	4	1.875	-	8	6	0	<1	2	1.25	-
LAG6	35	0	0	20	16,000	1813	800	35	6	0	<10	800	146.3	80

*Censored Data handled by substitution:
(Present>QL=1.1*Upper Quantification Limit; *Non-Detect=0.5*Lower Quantification Limit;)



The following graphs show (boxplots) of the results of fecal coliform bacteria monitoring at Trends Program sites by site for each sub-watershed grouping (Lagunitas, Walker, Coastal and Bay sites) A boxplot displays information about the range and distribution of data within the range (see figure at right). For the graphs in this report, the whiskers extending above and below the box are 1.5-times the middle 50% range box, with outliers shown by the asterisks (*). This treatment, which is a common variation on traditional boxplots whose whiskers extend to the minimum and maximum values, allows for the identification of outliers and extreme outliers that demonstrate the distribution and frequency of such results.

To present the data in the most useful form, outliers are omitted from the fecal coliform box-plot graphs below, but are included in graphs in Appendix D of this document.

Figure 38 – Lagunitas Creek Watershed Sites Fecal Coliform by Water Year

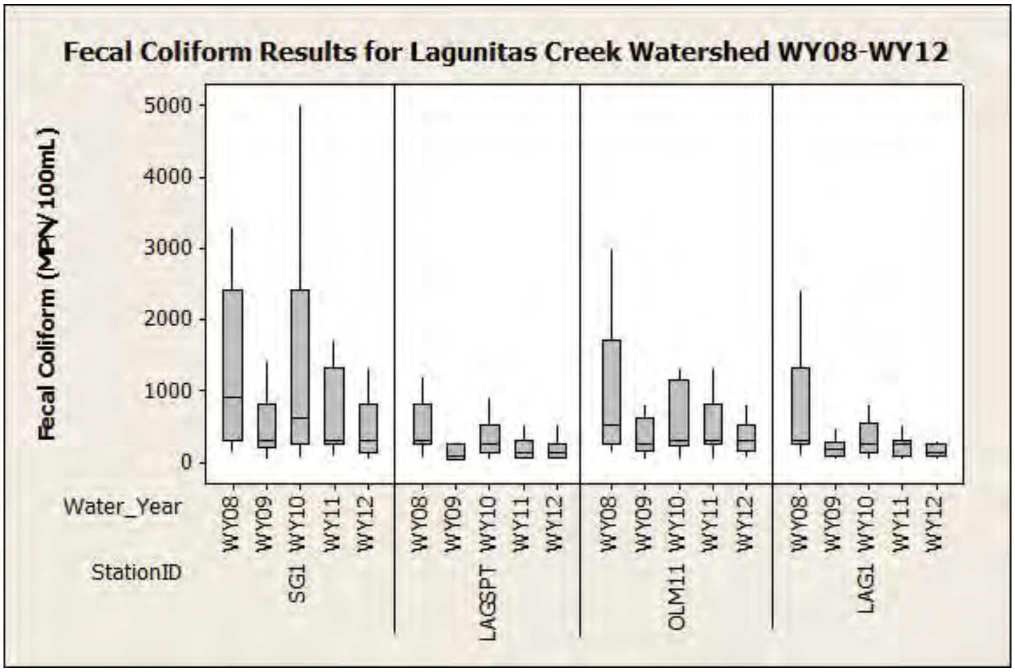
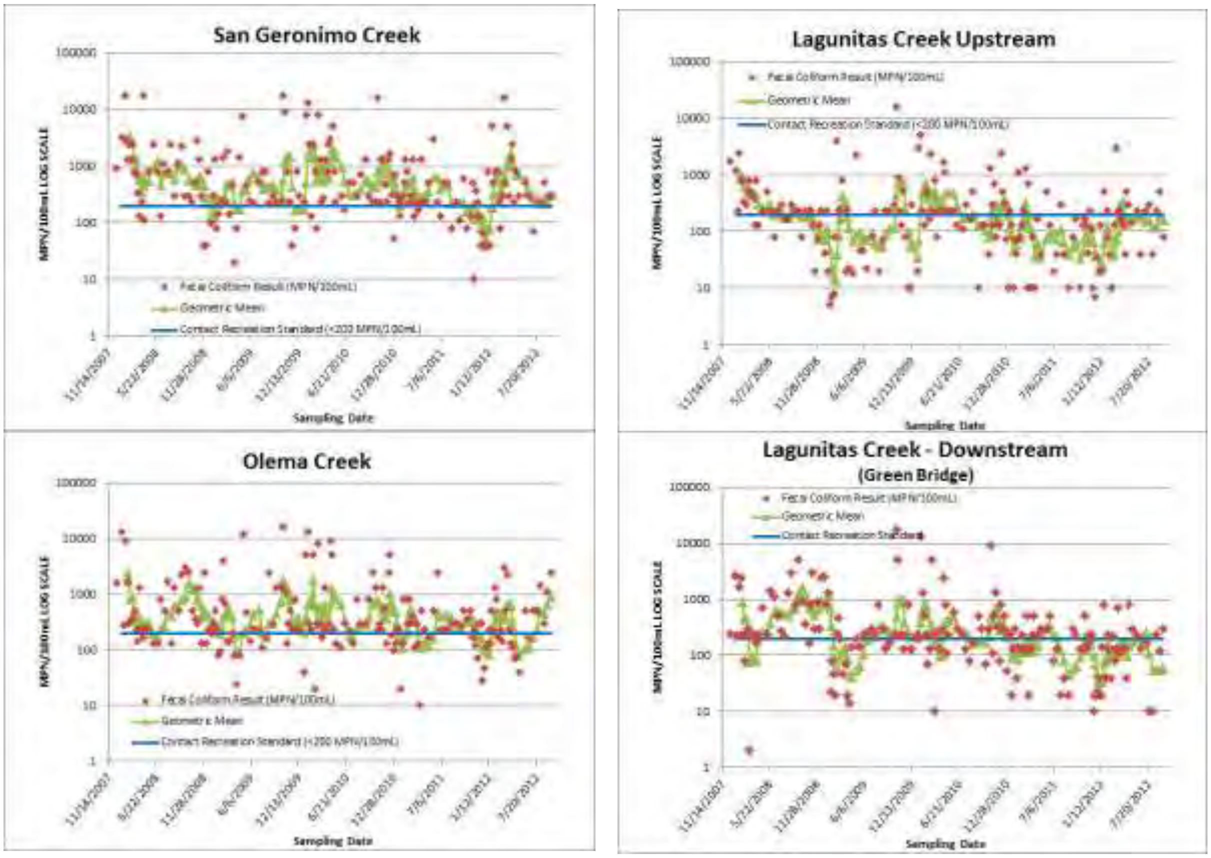


Figure 39 - Fecal Coliform Trends from sites in the Lagunitas Creek Watershed



The coliform bacteria results from the Lagunitas Creek watershed demonstrate elevated bacterial pollution in the watershed. The RWQCB set a contact recreation standard for fecal coliform bacteria that the 90th percentile of all samples should not exceed 400 MPN/100mL and that the geometric mean of five consecutive samples should not exceed 200 MPN/100mL.

An analysis of Trends program results show that during the program monitoring (Dec. 2007-Sept. 2012), over 33% of all samples from the Lagunitas Creek watershed (not including LAG6) exceeded the contact recreation single sample objective for fecal coliform bacteria.

Considered by water year, sites in the Lagunitas Creek watershed exceeded the single-sample objective in 43% of samples from WY08, 27% of samples from WY09, 34% of samples from WY10, 28% of samples from WY11 and 20.5% of samples from WY12.

Of the five sites in the watershed, two showed a high percentage of exceedences over the period of record: San Geronimo Creek (SG1) with over 49% of site samples (84:170), and Olema Creek (OLM11) with nearly 38% of site samples (64:170) exceeding the contact recreation, single-sample fecal coliform objective.

Figure 40 – East & West Shore Tributary Sites Fecal Coliform by Water Year

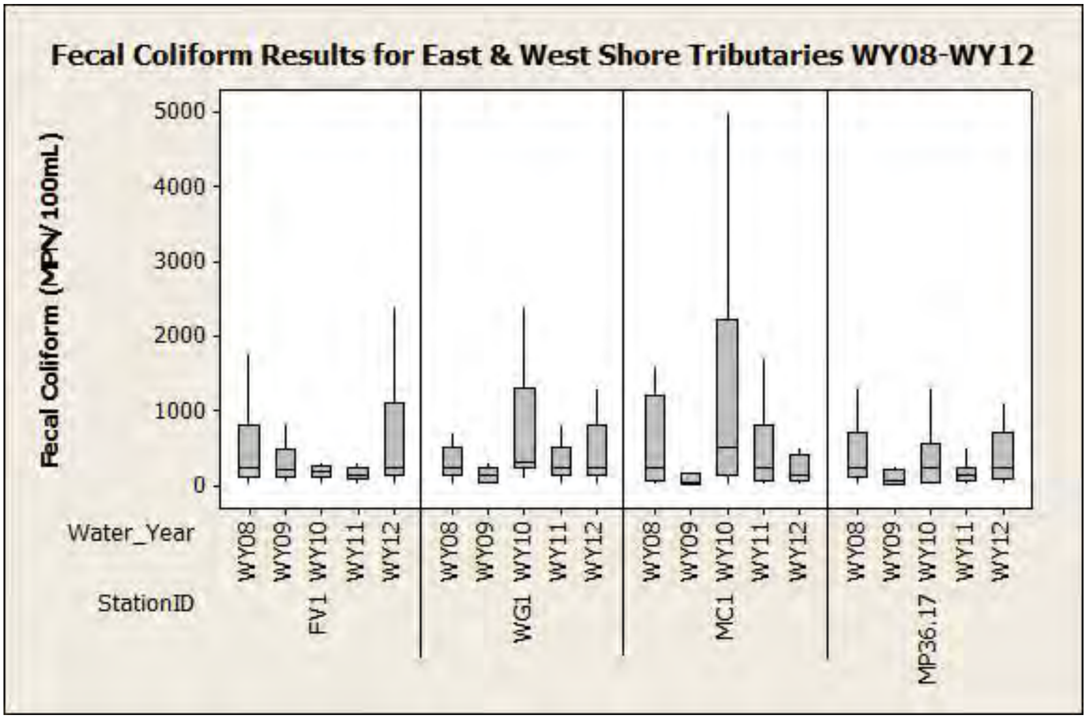
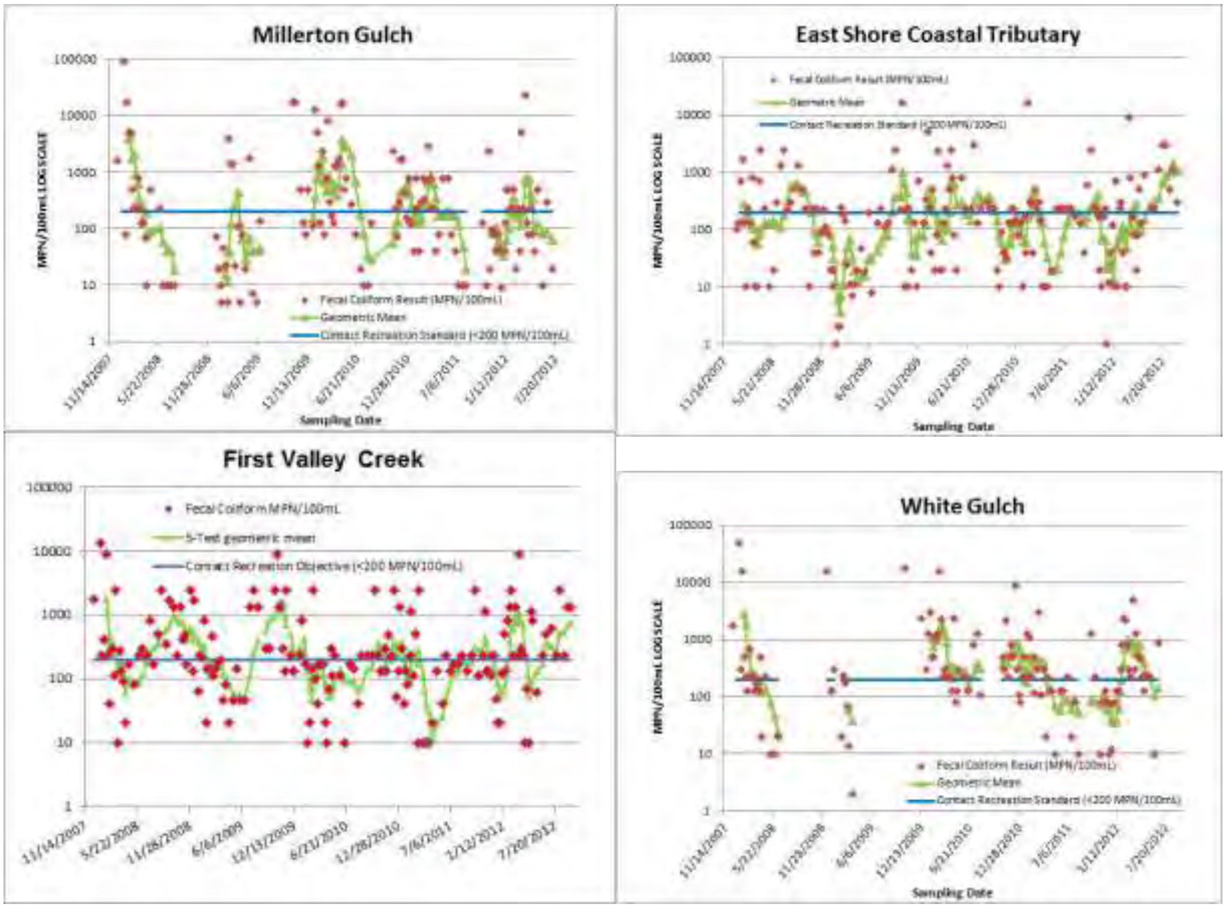


Figure 41-Fecal Coliform Trends from Sites on East and West Shore Tributaries



The coliform bacteria results from the four sites in small coastal watersheds draining directly to Tomales Bay demonstrate a contribution of bacterial pollution in the watershed even from these small drainages, although loading rates are a small fraction of those from the two large drainages in the watershed. Overall, results from the four sites on coastal drainages show over 29% of samples (171:586) from Dec. 2007-Sept. 2012 exceeded the contact recreation single-sample fecal coliform objective. Considered by water year, sites in the coastal watersheds exceeded the single-sample objective in over 35% of samples from WY08, over 18% of samples from WY09, over 36% of samples from WY10, over 22% of samples from WY11, and over 31% of samples from WY12.

The coastal watershed with the highest percentage of single-sample exceedences during the period of record was Millerton Gulch (MC1) with over 35% of site samples (47:132) exceeding the single-sample contact recreation standard for fecal coliform. The second highest percentage of single-sample exceedences was seen at White Gulch (WG1) with over 34% of site samples (40:117) exceeding the contact recreation standard.

Figure 42 – Walker Creek Watershed Sites Fecal Coliform by Water Year

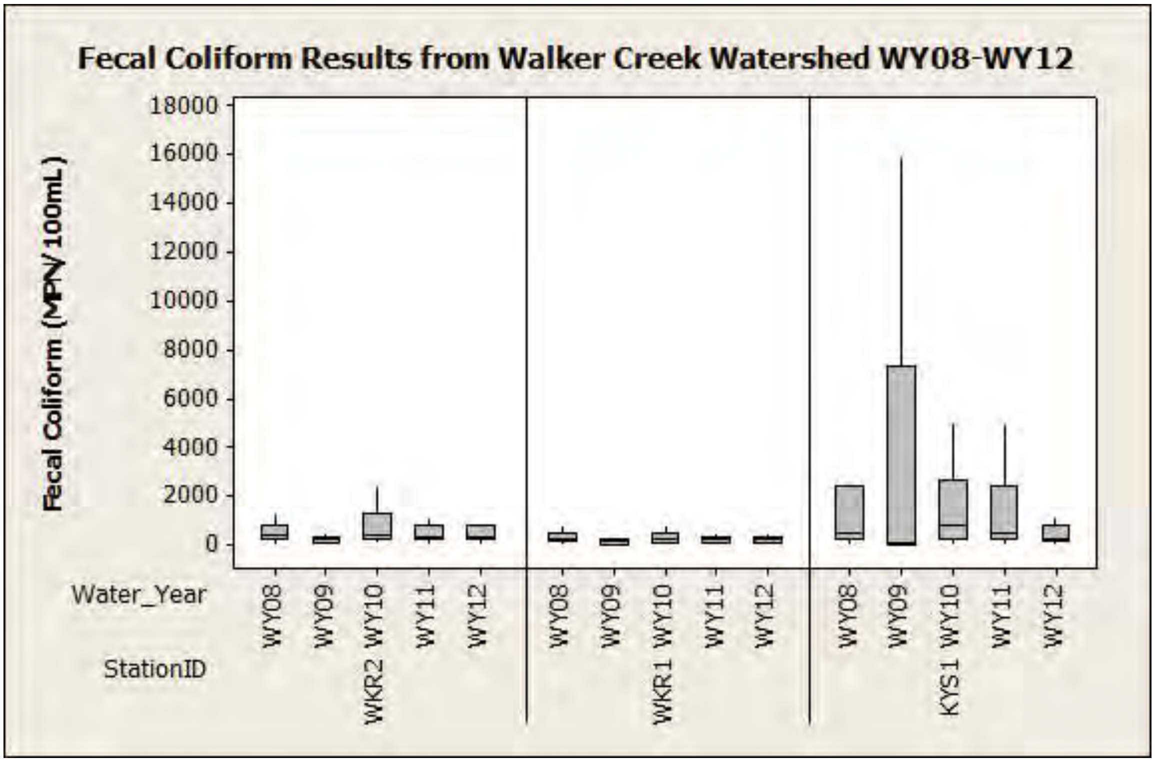
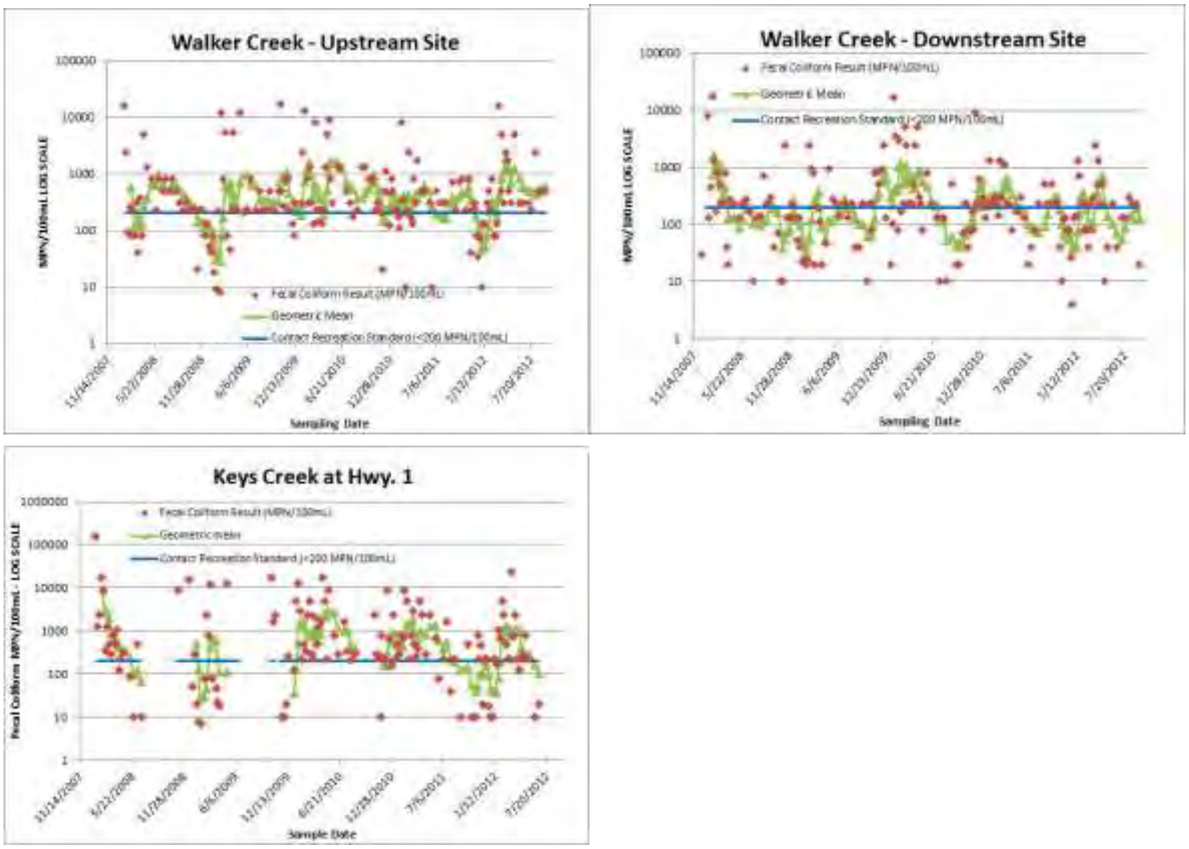


Figure 43 - Fecal Coliform Trends from Sites in the Walker Creek Watershed



The coliform bacteria results from the three sites in the Walker Creek watershed also demonstrates elevated bacterial pollution in the watershed. An analysis of Trends program results show that over the program duration (Dec. 2007-Sept. 2012) over 37% of all samples from the Walker Creek watershed (175:468) exceeded the contact recreation single sample objective for fecal coliform bacteria.

Considered by water year, sites in the Walker Creek watershed exceeded the single-sample objective in nearly 43% of samples from WY08, over 23% of samples from WY09, 49% of samples from WY10, over 37% of samples from WY11 and over 33% of samples from WY12.

Of the three sites in the watershed, two showed a high percentage of exceedences over the period of record: Upper Walker Creek (WKR2) with almost 42% of site samples (70:167), and Keys Creek (KYS1) with almost 49% of site samples (64:130) exceeding the contact recreation, single-sample fecal coliform objective.

Figure 44 – Tomales Bay Sites Fecal Coliform Results by Water Year

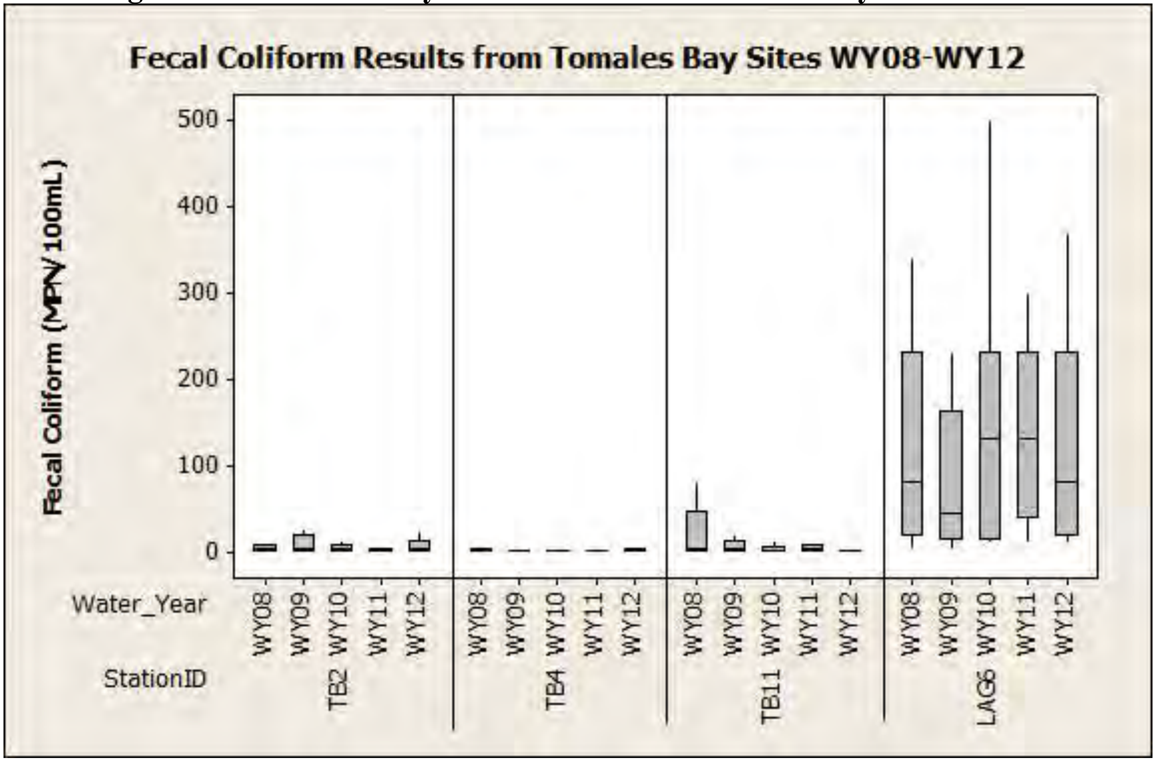


Figure 45 – Outer-, Mid-, and Inner-Bay Sites Fecal Coliform by Water Year

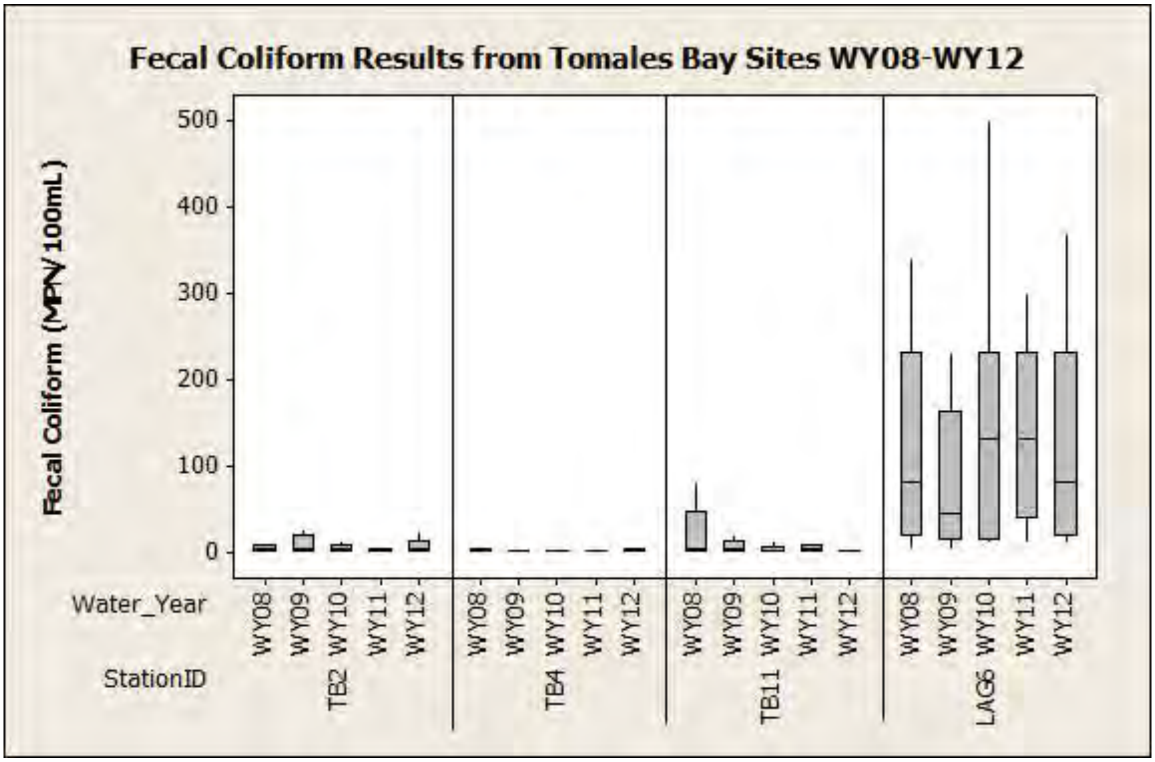
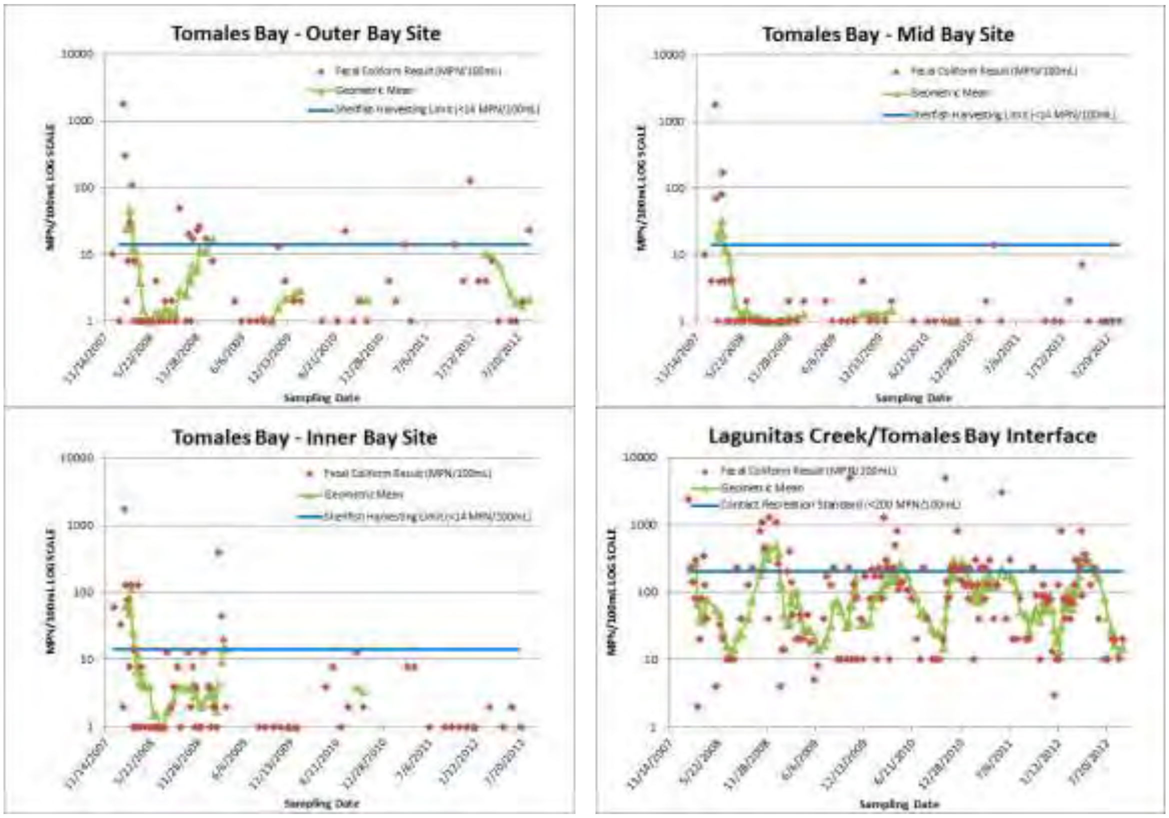


Figure 46 - Fecal Coliform Trends from Tomales Bay Sites



An analysis of Trends program results show that over the program duration (Dec. 2007-Sept. 2012) almost 9% of all samples from Tomales Bay sites (Outer-, mid-, and inner-Bay sites only) exceeded the contact recreation single sample objective for fecal coliform bacteria. This value is well within the contact recreation standard of 400 MPN/100mL, and under the more appropriate shellfish harvesting objective of 43 MPN/100mL. It should be noted the Bay sites were not sampled during rainfall closures during the winter, so the assessment of true water quality conditions year-round cannot be assessed through this program data.

Considered by water year, Tomales Bay sites exceeded the single-sample objective in about 19% of samples from WY08 (which included some winter samples), over 4% of samples from WY09, 0% of samples from WY10 and WY11, and over 3% of samples from WY12.

Our data from sites in Tomales Bay suggest acceptable conditions that meet state and federal water quality objectives for bacteria at least during the dry season. It should be understood, however, that data from Bay sites during storm events, or Bay closure were *not* collected beginning in WY09, making a true assessment of Bay water quality under year-round conditions not possible.

Conclusions

The results presented in this report demonstrate that the Tomales Bay watershed faces significant water quality issues related to bacteria, nutrients and sediment. In general, fecal coliform (FC) results show that all tributaries fail to meet RWQCB objectives for contact recreation during some of the year, with the highest percentage of exceedences occurring in the San Geronimo Creek, Olema Creek, and Walker Creek watersheds. Usually, sites in Tomales Bay met RWQCB shellfish harvesting objectives for most samples, with exceedences occurring during storm events. Most tributary sites met RWQCB objectives for dissolved oxygen and pH. Those tributaries that failed to meet these objectives were intermittent streams that do not support salmonid species. Analysis of sediment parameters suggests that there are significant sources of sediment affecting most tributary sites during the wet season. Nutrient analysis shows relatively high levels of nitrogen in the tributary systems, with many sites having mean nitrate plus TKN values that exceed the EPA recommended criteria of 0.38 mg/L Total Nitrogen for our region’s rivers and streams. On the other hand, our results demonstrate very low or undetectable levels of either ammonia or phosphorus during WY08-WY10 sampling. The ample available nitrogen, and the low levels of phosphorus suggest that phosphorus is the limiting nutrient in the watershed. The results from nitrate and total Kjeldahl nitrogen analyses show periodic spikes (usually related to storm events), and suggest that organic nitrogen is the largest type of nitrogen in watershed surface waters.

Initial analysis of gathered data compared with rainfall data suggests that there are not discernible downward trends in pollutant concentrations across the watershed during the five years of monitoring data. Storm-related runoff appears to be the primary driver of adverse water quality conditions including bacteria, nutrients and sediment levels, and that subwatershed-level results reflect land-use patterns across the watershed. The program has maintained consistent water quality monitoring during five wet-seasons, capturing significant climatic variability which should allow for a more robust analysis of both legacy data and future TBWC program data for detectable long-term trends.

Data Limitations

It is significant and necessary to note that the results shown for the WY08 ranges reflect less than a full water-year of sampling data because sampling was not initiated until December 17th, 2007. The WY09, WY10, WY11 and WY12 results that are reported cover the full water-year (October 1-September 30 of the corresponding year).

All ranges listed reflect certain treatment of censored data. For the purposes of field parameters, all measurements that failed quality controls were excluded, all censored bacteria data was handled by substitution using the following rules: 1) If the result was less than the reporting limit, one-half of the lower reporting limit was substituted; 2) If the result was greater than the reporting limit, 1.1 x the upper reporting limit was substituted. For nutrient parameters, because of the significant number of non-detect results, the following data handling rules were followed: if non-detects represented less than 50% of results, descriptive statistics were generated using Kaplan-Meier which assumes no distribution; if non-detects exceeded 50% of the sample results, descriptive statistics were generating using MLE (Maximum-Likelihood Estimation). This treatment of non-detect water quality data is recommended by Helsel (2005).

During the period from the end of December 2008 through May 2009, nutrient analyses were conducted by a different commercial lab than was used for the rest of the program data. This lab had a reporting limit for Ammonia results at (0.5 mg/L) which is in contrast to the lower reporting limit for the remainder of the ammonia data (0.1 mg/L). The difference in reporting limits is responsible for the seemingly elevated levels shown in the WY09 ammonia graphs. Without omitting non-detect ammonia results from this period, there is no way to remove this artifact.

During WY09, logistical constraints of sampling partners forced a reduction in sampling frequency for sites in Tomales Bay (TB2, TB4 and TB11). From that point forward samples were collected only once per month when compliance samples for CA DPH were being collected. Consequently, Tomales Bay sites were not regularly sampled during the wet season due to logistical constraints of sampling partners; this means that we cannot assess year-round water quality conditions in Bay waters using our program data.

It is one of the goals of the project to leverage existing data from outside agencies and groups to extend the range of inference for water quality trends. In future reports the program will include this data, where available, in the appropriate analyses. For a discussion of this data compilation, see the Data Management and Legacy Datasets section of this report.

Source Area Monitoring

Source area monitoring efforts are focused on identifying sources and quantities of water pollutants to Tomales Bay and its freshwater tributaries. While Trend monitoring is dependent on long-term sampling at a suite of permanent sampling sites, source area monitoring is both flexible and responsive based on the data collected. The intent of source area monitoring is to support and prioritize future watershed or sub-watershed water quality improvement efforts, and to document conditions in order to evaluate the effectiveness of past efforts to improve water quality on private and public lands. This program builds on stormwater monitoring conducted in 2006 in the stormwater systems in the towns of Woodacre, Tomales and Point Reyes Station. More details on this project are detailed in a TBWC report (TBWC 2006).

Sampling sub-watersheds and sites are determined based upon the results of previous sampling and through prioritization of known source areas by the Water Quality Technical Advisory Committee (WQ TAC). Priority sub-watersheds for the 2008 water year were selected and finalized at a meeting of the WQ TAC in October, 2007. During the first year, monitoring of the rural stormwater sub-sheds continued, along with Heart's Desire State Park. The WQ TAC met again in June 2008 to begin to reprioritize potential source areas for sampling during the 2009 water year. Results of source area sampling are presented to WQ TAC members at regular meetings, and with involved groups in the prioritized areas where appropriate.

Data from source area sampling in the 2008 water year was detailed in the 2007-08 Annual Water Quality Report (Carson, 2008). Because the program funding was suspended due to the state financial crisis during the 2008-09 wet season, the source area element of the program was suspended before significant rainfall occurred. At a meeting in September 2009, the WQTAC decided that two of the sub-watersheds (Tomasini Creek and Keyes Creek) that had been selected for 2009 should be sampled during the 2009-10 wet season. In addition, we would continue sampling on Third Valley Creek during storm events, and coordinate with the Salmon Protection And Watershed Network (SPAWN) to analyze data from samples on San Geronimo Creek. Results of this sampling were presented to the WQ TAC in April 2010. The difficulty of accessing some sites in these sub-watersheds has hampered our ability to collect sufficient data to define source areas in many of these small watersheds. Other issues are the timing of storms, and the varying response of different watersheds to rain events.

In order to improve the useful data coming out of the Source Area Program, the WQ TAC determined that remaining Source Area Program funding would be used to target selected Trends sites in major watersheds with intensive sampling (i.e. rising, falling limb, 1, 2 and/or 3,4, 5-days after a significant rain event) around 3-5 storm events each winter. The goal would be to gain an understanding not only of the magnitude and duration of pollutant loading in major contributing sub-watersheds, but also whether there are thresholds of precipitation that correspond to loading events. This methodology was implemented during the 2011 water-year, and took place at our Trends Program sites in the Millerton Gulch and San Geronimo, Olema and First Valley Creeks. The close spacing of storms during WY11 frustrated attempts to gather the latter (day3-5) samples, however differences between monitored watersheds were observed.

Source Area program results for WY10, WY11 and WY12 are detailed in Appendix F to this document. There was no Source Area Program sampling during the 2009 water year. And results funded under previous funding agreements from WY08 was previously reported.

Giacomini Wetland Restoration Water Quality Monitoring

This project funded portions of the Giacomini wetland restoration, and the long-term monitoring of the project area and in nearby reference marshes. The results and analysis of the monitoring conducted by the National Park Service, Point Reyes National Seashore is detailed in the report: *Year Four of the Giacomini Wetland Restoration Project: Analysis of Changes in Water Quality Conditions in the Project Area and Downstream* by Lorraine Parsons (NPS) which is included in this report as appendix A.

Quality Control

Quality Assurance and Quality Control for this project were implemented following the approved Quality Assurance Project Plan (Carson 2007). A summary of those measures is provided here, but detailed information is available in the source document.

Field equipment was calibrated at the beginning of each sampling day including: a three-point calibration was performed for all pH meters, and dissolved oxygen was calibrated with a one point calibration with water-saturated air. Calibration checks were performed immediately following each calibration, and again at the end of the field day, in order to monitor for fouling and drift and to ensure that the instruments stayed within the calibration acceptance criteria of each parameter.

In order to assess precision, core parameters (field measurements) and grab samples were both collected in duplicate once per sampling day. The duplicate samples were submitted to the professional laboratories for testing. Additionally, field blanks (a complete bottle set filled with distilled water using rinsed field sampling equipment) were collected each sampling day and submitted for laboratory analysis in order to detect and quantify possible sources of sample contamination. Laboratory quality control measures included: matrix spikes, method blanks, laboratory control spikes and equipment calibration.

Measurement Quality Objectives

The program established measurement quality objectives (MQOs) for all monitored parameters. There are MQOs for calibration acceptance, precision and systematic error (percent recovery). Measurement of systematic error (reported as percent recovery) is a measure of the accuracy of the laboratory procedures and equipment, which is determined by conducting matix spikes or laboratory control spikes, to test a known value of a particular analyte. The MQO of systematic error (percent recovery) is stated in the project QAPP as 80-120% for nitrate and ammmonia as N, TKN and phosphorus. The professional laboratories that conducted program analyses flagged any results for which corresponding QC results were outside MQO’s. We did not report any such results and had only two instances over the course of the program.

The MQOs for precision are defined in the project Monitoring Plan and QAPP as the acceptable thresholds of relative percent difference (RPD), calculated from the duplicated QC sample sets. The precision MQO for nitrate (as N), TKN, phosphorus and ammonia (as N) is +/- 25% RPD. The MQO for total coliform and fecal coliform is that the log of the difference between duplicate sample results be within 3.27 x the mean log difference between all paired tests. The MQO for Turbidity is +/- 2 NTU or 5% RPD, whichever is greater. The details of the project precision MQO is shown in tables 7 and 8 below.

A total of 1172 duplicate QC samples were collected during the project from WY08-WY12; 26% of these (309:1172) included a censored result (non-detect) which prevented calculation of RPD/precision. Because of this limitation both the mean RPD value and the Number of QC Duplicates that Failed to meet MQO for RPD (in Table 7) are calculated only from those QC tests that had quantifiable RPD (i.e. did not include a censored result).

Table 7: Precision of Duplicate Lab Samples from Water Years 2008-2012

	Ammonia as N (mg/L)	Nitrate as N (mg/L)	TKN (mg/L)	Phosphorus (mg/L)	Total Coliform (MPN/100mL)	Fecal Coliform (MPN/100mL)	Turbidity (NTU)
Total Number of QC Duplicates	103	178	177	101	152	168	293
Number of QC Duplicates with Measurable RPD[1]	0	119	155	4	143	152	290
Number that Failed to Meet MQO for RPD[1]	-	1	22	1	0	2	8
Mean RPD[1] (Precision)	-	4.83%	17.75%	15.59%	mean R_{log} = **0.342**	mean R_{log} = **0.332**	6.63% for all dups (only 8 were outside ±2NTU)
Project MQO for RPD (Precision)	±25%	±25%	±25%	±25%	R_{log} within 3.27 x mean R_{log} = **within 1.1182**	R_{log} within 3.27 x mean R_{log} = **within 1.0844**	±2 NTU or ±5%, whichever is greater

[1] Many duplicate QC measurements did not have measurable RPD because the sample, the dup or both had a censored result; therefore, the calculated mean RPD values and number of failures do not include all duplicate QC measurements collected during WYs 2008-2012.

Table 8: Precision of Duplicate Field Measurements from Water Years 2008-2012

	Water Temperature (°C)	Specific Conductance (µS/cm)	Salinity (ppth)	Dissolved Oxygen (mg/L)	pH
Total Number of QC Duplicates	210	211	211	209	190
Number of QC Duplicates with Measurable RPD[1]	210	211	211	209	190
Number that Failed to Meet MQO for RPD[1]	2	3 > 3% 2 > 5 µS/cm	1	2	1
Mean RPD[1] (Precision)	0.69%	0.37%	0.10%	0.31%	0.39%
Project MQO for RPD (Precision)	± 0.5°C	± 5 µS/cm or ±3% whichever is greater	± 5%	± 5%	± 0.2 pH units

The number of quantifiable duplicate lab samples that failed to meet the MQO for precision was relatively low, given the large number of samples collected over five years. There were no quantifiable duplicate samples for Total Coliform which failed to meet the stated precision MQO. There were only one each for Nitrate and Phosphorus, and only two for Fecal Coliform. There were slightly more for both Turbidity and TKN (8 and 22 respectively). The mean RPD for all lab parameters was well within the project MQO's for precision, except for Turbidity which has dual standards and was only slightly larger than the MQO percentage standard. There were very few duplicate field measurements that failed to meet the precision MQO's, and each of their mean RPD's were well within stated objectives.

In many cases, there were higher rates of lab precision MQO failure during the period from December 2008-June 2009 when the project was operating under the state budget freeze and using support from the SF RWQCB-contracted lab to process some lab samples. The secondary lab had different detection levels and lower performance on QC tests than the primary laboratory used for all other program samples for the duration of the program. Most lab results from the secondary lab during this period passed QC checks and are included in this report's analyses; however, invoices for the analyses at the secondary lab were not paid with grant funding from this program.

Data Management and Legacy Datasets

Program data has all been verified through the project's QA/QC measures and is integrated into the TBWC water quality database. Program staff has been working with staff at the San Francisco Estuary Project to facilitate the migration of our direct project data into the CEDEN data system, enabling access by a wide audience, including regulators. A copy of all program data will be submitted to the SWRCB with this final report. In addition, we continue to pursue outside datasets focused on water quality in the Tomales Bay watershed.

One of the goals of this project is to research, collect and compile reliable baseline data describing the concentrations of contaminants in the waters of Tomales Bay and tributary streams. This is being accomplished through the population of a water quality database with legacy data sets provided by outside agencies and groups who have collected water quality data in the watershed. The establishment and population of a water quality monitoring database for the entire watershed and the capacity to analyze data and to develop trends, will benefit the agencies and organizations that are currently collecting data, and those responsible for tracking and protecting water quality.

Progress on this objective was significant during the five years of this program. An EPA-STORET-compatible Access-based database developed by the NPS (accessible online at: http://www.nature.nps.gov/water/vitalsigns/vitalsignsmgt.cfm) is being used to collect, compile and analyze data for this program. All relevant metadata regarding the project, stations, and sampling events was created. Results from this program have been entered into this database through the current sampling events, and the reports and descriptive statistics included in the appendices of this report were produced using imbedded reporting functions.

In addition to data from this program and the related sub-projects, datasets from outside groups and agencies have also been obtained, and are currently in the process of documentation and entry into the system. See Appendix E for a table summarizing water quality datasets that have been documented and imported into the TBWC water quality database thus far. Additional datasets remain to be imported, including several from several decades ago (Smith et. al. 1971 and Sharpe 1974) which should provide a means to compare long-term pollutant concentrations from watershed sources. The largest challenge associated with these data sets is the documentation of metadata including precise sampling location, analytical methods and detection limits, and the nature of quality control measures to evaluate the quality of the data. A SWAMP-compatibility checklist was developed and distributed to members of the WQ TAC and to outside agencies and groups in order to expedite the metadata documentation and data entry processes. This checklist will guide continued efforts to compile watershed data.

Ultimately, this compilation of watershed water quality data is of central importance to extend the period of inference in the determination of long-term trends. Because some of the sampling locations of these outside programs are the same as those in the current effort, this should be directly relevant to such a comparison.

Appendix E provides a summary table of water quality datasets that have been identified and documented for import into the TBWC water quality database. The summary provided the source group, the project, the time period covered by data, outline of sites and sampling watershed, parameters and status of the dataset's of inclusion in the TBWC Water Quality database. Datasets that are imported will be provided to inform future analysis of water quality conditions in the watershed.

A web-based data communication effort to allow for direct dissemination of some Trends project results to the public through the TBWC website was active throughout this project. All fecal coliform data for all Trends program sites is available, as well as graphs of individual results, the five-test geometric mean of fecal coliform and the appropriate water quality objective. The individual site pages can be accessed at http://www.tomalesbaywatershed.org/trendmonitoring.html This page will be maintained by the TBWC for the foreseeable future after this funding expires. This effort provides members of the public to view recent water quality conditions at Trend sites and mean conditions for past years, as well as a comparison to the appropriate use standard for each site.

Outreach and Education

Outreach and education activities through this funding included: the publication of two printed bulletins; hosting a State of the Bay conference; development and delivery of monthly electronic newsletters; participation in teacher training; numerous presentations to partner organizations, students and the public; electronic outreach and maintenance of our on-line water quality data resource.

The water quality program management provided monthly updates at both TBWC Board of Directors/Executive Committee meetings and full Council meetings on program and grant activities. In addition, regular Water Quality TAC meetings were held to provide an opportunity to discuss monitoring results, program priorities and program budget matters. The Program Manager presented various aspects of and results from monitoring activities: 1) at public meetings of partner organizations including: Marin Resource Conservation District (MRCD), Lagunitas Technical Advisory Committee, Point Reyes National Seashore and Trout Unlimited; 2) at Scientific Conferences and Symposia; and 3) through education and training opportunities with: the West Marin School through

NOAA's B-WET program, Tomales Middle School science program, SPAWN's ongoing seminar program for science educators, Dominican University of California and the East Bay Academy for Young Scientists.

In the Fall of 2008, the Tomales Bay Watershed Council published our seventh printed Bulletin, a report to residents and visitors throughout the Tomales Bay region. The Bulletin was focused on the implementation of the Giacomini Wetlands Restoration Project, the TBWC's water quality monitoring program, and on measures to protect the watershed through the grazing waiver and septic solutions. In the Spring of 2011, the Council published our eighth printed Bulletin which focused on sharing some of the topics explored during the 2010 State of the Bay Conference including fascinating research, monitoring and restoration efforts taking place throughout the watershed. In both cases over 7,000 copies of the Bulletin were printed and distributed to every boxholder in the watershed, to our partner organizations and to the public through various outreach events, and through our website. Electronic copies of the Bulletins are available at: http://www.tomalesbaywatershed.org/informationreports.html

On October 22nd and 23rd, 2010, the Tomales Bay Watershed Council presented the **State of the Bay 2010 - A Conference about Tomales Bay and its' Watershed**, gathering leading scientists, agency representatives and policy-makers with an interest in Tomales Bay and its watershed. It was the fifth State of the Bay Conference, but the first in ten years. It was a successful event, gathering nearly 100 people each day to learn about the current state of scientific knowledge, resource management and the state of important resources in the watershed from twenty-seven scientists, policy makers, non-profit organization leaders and stakeholders.

Complete digital proceedings are available on the conference webpage of our site: http://www.tomalesbaywatershed.org/stateofthebay2010.html

Conference agenda, short biographies, presentation abstracts, and presentations are available for download as pdf's, and the conference was video-taped and individual presentations can be viewed through links at our site.

After this funding agreement had closed, the Council also organized and sponsored the 6th State of the Bay Conference on October 26th, 2012 which included summaries of funded activities from both the Giacomini Wetland Restoration Project and TBWC water quality monitoring programs.

The Council's electronic outreach was enhanced during this program funding, enabling the public greater access to timely water quality results, water contact advisory conditions, and important local events and topics of interest concerning the watershed. This was achieved largely through the support of electronic newsletters that were sent to roughly 600 subscribers each month, and through the regular updates of online results and analysis of water quality data for each of the Trends Program monitoring sites. An archive of the electronic newsletters is available at our website: http://www.tomalesbaywatershed.org/informationreports.html and water quality data and analysis for each Trends Program site is available here: http://www.tomalesbaywatershed.org/trendmonitoring.html

The TBWC also maintained a webpages showing current water contact advisory conditions in the watershed during the recreation season (April-October).

Outreach and education are an on-going and important element of both this program and the Council's mission to foster understanding of watershed issues.

Next Steps for the Program

The Tomales Bay Watershed Council water quality monitoring program as described in this report began in the winter of 2007 and continued through the end of the 2012 water year. As the program funding through this grant ends, the Council will continue monthly monitoring at all Trends program sites using emergency funding and will engage in a fundraising and outreach effort to secure funding for every year to come. With the existing data from this program, combined with legacy data we have compiled and continued monitoring, the Council is committed to documenting the long-term water quality trends in the Tomales Bay watershed.

The Source Area Program, which provided small-scale examinations of subwatersheds to determine relative contributions to pollutant loads, was concluded during the 2011-12 winter. We will continue to support the monitoring work of our partners, like Trout Unlimited and will be available to conduct source area monitoring as funding allows.

The Giacomini Wetlands Restoration Project water quality monitoring continued quarterly monitoring of project and reference areas through September 2012. Funding for this monitoring after September 2012 will depend on the available resources of the organizations involved in monitoring the long-term impacts of this restoration project.

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Appendix A: Year Four of the Giacomini Wetland Restoration Project: *Analysis of Changes in Water Quality Conditions in the Project Area and Downstream*

By: Lorraine Parsons, Wetland Ecologist, Point Reyes National Seashore

December 7, 2012

Photo by Galen Leeds Photography

Executive Summary

In 2007-2008, the National Park Service (Park Service) and Point Reyes National Seashore Association (PRNSA) implemented an approximately 613-acre wetland restoration project in the southern end of Tomales Bay in Marin County, California. The project principally focused on conversion of a former dairy ranch into tidal wetlands, as this area was once historically. However, rather than try to recreate historic conditions, the Park Service focused on restoring natural hydrologic tidal and freshwater processes, thereby promoting restoration of hydrologic and ecological functions. Natural hydrologic processes are the cornerstone of many hydrologic and ecological functions and economic “services” associated with wetlands. Perhaps, one of the most important functions that wetlands can play -- particularly in Tomales Bay -- is water quality improvement. While it is generally perceived as pristine, this rural coastal watershed still suffers from negative anthropogenic influences such as agriculture, home and road development, leaking septic systems, mercury mining, landfills, and oil spills. During the last few decades, poor water quality in the Bay has forced oyster fisheries to close down several times and, in 1998, was associated with a virus outbreak.

As an integral component of the restoration project, the Park Service has implemented a comprehensive long-term monitoring program to assess whether restoration is successful. To facilitate analysis of restoration progress, the Long-Term Monitoring Program relies on a modified BACI (“Before-After, Control-Impact”) sampling framework. The Giacomini Wetlands and another restoration site, Olema Marsh, represent the Impact Area, while Reference or Control Areas were established in natural tidal marshes in Tomales Bay and adjacent watersheds to facilitate a comparative evaluation of changes in the restored system relative to ambient conditions. In addition, sampling was also conducted on the upstream perimeter of the Project Area (Upstream Areas) to more clearly understand the quality of inflow waters to the Project Area. Monitoring of these areas occurred both four- to five years before and four years after restoration, as well as two years in between these periods when cows were removed, but levees were still present (Passive Restoration). A key component of this monitoring program has been water quality monitoring, which has included monthly to quarterly systematic sampling of water quality field parameters within these Study Areas. Parameters include nutrients (nitrate, nitrites, total ammonia, total phosphorous, total dissolved phosphates or dissolved orthophosphates), and pathogen indicators (total and fecal coliform). This technical memorandum summarizes changes in water quality conditions within the Project Area during the fourth year after restoration for Water Year (WY) 2012.

Some improvement in water quality conditions were expected immediately following restoration due to decreases in residence time for leveed waters. However, these improvements were expected to be tempered to a large degree initially by pulses in sediment and nutrients from re-working of exposed soils by tides, floods, and decomposition and mineralization of pasture vegetation, with variables such as pH and dissolved oxygen (D.O.) responding accordingly to the resulting flux in nutrients. During the first several years after restoration, the speed with which conditions improved within the Project Area for variables such as dissolved oxygen and nitrate and fecal coliform concentrations far exceeded our expectations, and expected issues as discussed above with large temporary increases in turbidity and temporary decreases in dissolved oxygen did not materialize or were not as dramatic as anticipated. At least initially, some of this may have partially resulted from the fact that Year 1 or WY 2009 was a dry year, and few large storms occurred that would have contributed to reworking of this evolving landscape, even though some of the few larger storm events that did occur were captured. Even in the second year, which was much wetter, there were no overbank flooding events. Despite the lack of storms, reworking of the landscape did occur, largely due to reintroduction of tidal action, with shoals evident at the mouth of newly created tidal channels due to sediment efflux from the marsh (KHE 2009). Later years were wetter and even included an overbank flooding event, but, still, through Year 4, water quality conditions have improved much more quickly than anticipated without the degree of short-term adverse impacts that were originally predicted.

With some exceptions, water quality parameters have shown significant, positive improvements in conditions between Pre- and Full-Restoration phases (Table 1). Dissolved oxygen levels increased 14%, while nitrate, ammonia, phosphate, phosphorous, and fecal coliform levels decreased at least 23%, with some of these parameters falling quite substantially (90%). Somewhat expectedly, nitrate and fecal coliform loading and turbidity have increased since restoration, although the latter was not as dramatic as was anticipated (49%). Loading was certain to increase, given that the ranch was largely diked before and not contributing fully to pollutant loading to Lagunitas Creek except during extreme flood stages.

As might be expected, salinity in the Project Area climbed 70% relative to the diked dairy ranch conditions due to increased tidal influence. This same influence was expected to increase temperatures relative to the diked dairy conditions, however, temperatures unexpectedly dropped 6%, probably because residence time of waters decreased, and exchange with other water bodies increased, even if estuarine waters are often warmer than freshwater ones. Over the short term, pH was expected to decrease or remain the same, with the acid-producing effects of oxidation of organic matter and production of acids being countered to some degree by introduction of higher pH tidal waters. Not surprisingly, then, the pH within the restored wetland has declined 5% since the levees were breached.

After only a short time (four years), most of the parameters, including temperature, dissolved oxygen, ammonia, phosphates, phosphorous, and seemingly at least median concentrations of nitrates were actually statistically equivalent to Reference Areas (Table 1). Even turbidity levels in the Project Area showed no statistical difference with those in Reference Areas, despite the fact that they had increased relative to Pre-Restoration conditions in the Project Area.

Restoration appears to be the primary factor driving changes in levels of salinity, dissolved oxygen, turbidity, ammonia, and fecal coliform and loading rates of nitrates and fecal coliform in the Project Area since the levees were breached. However, the situation is not as clear cut for some of the other variables such as pH, temperature, nitrates, and phosphates, levels of which dropped in both the Project and Reference Areas between the pre- and post-restoration sampling periods. In the case of pH, the rate of decline was identical between the Study Areas, strongly suggesting that external factors such as the volume and distribution of rainfall and its effect on lower-pH freshwater inflow may more influence pH in the restored wetlands than any restoration-related factors such as release of acids from decomposition of organic matter or oxidation of soils. The same appears true appears true for temperature. However, the differences in the magnitude of change between the Project and Reference Areas for variables such as nitrates and particularly phosphates suggests that both restoration and climatic factors may be playing a role in shaping current water quality conditions in the restored wetland. Others factors also have an effect, including non-point source run-off: reductions in nitrates might even have been dramatic had mean levels not been artificially inflated by a non-point source run-off that flows into a freshwater marsh created as special status species habitat.

Perhaps, some of the most interesting results were those in which the trajectory of change differed completely between the two Study Areas. For example salinity decreased within natural marshes during the post-restoration sampling period, but increased considerably during this period in the Project Area: any climate-related reduction in salinities within these estuaries as a whole was obviously overwhelmed by the re-introduction of tidal waters to the artificially maintained freshwater environment of the former dairy ranch. Similarly, detection of total ammonia decreased in the restored wetland after levee breaching, but increased considerably in natural marshes. Factors driving this change are not understood, but similar increases have been observed at other sampling sites in the Tomales Bay during recent years (Rob Carson, TBWC, *pers. comm*.).

Ultimately, restoration of more than 600 acres of historic floodplain/marshplain is expected to not only restore water quality conditions within the Project Area, but Tomales Bay itself. Therefore, one of the most important indicators of the success of this project will be changes in concentrations and, even more importantly, loading between upstream and downstream sampling locations. As was expected, during the first four years after restoration, loading rates of pathogens and presumably nitrates actually increased in the Project Area relative to pre-restoration conditions, because, prior to levee removal, the pastures had either no direct connection to Lagunitas or other creeks (East Pasture) or only muted tidal connection (West Pasture) and, therefore, were only very infrequently in a position to contribute to downstream "loading." It is likely that watershed-scale benefits will take time to be realized due to the continuing evolution occurring within the Project Area, as pasture vegetation continues to die off and convert into more natural salt- and brackish marsh vegetation communities.

Introduction

In 2007-2008, the National Park Service (Park Service) and Point Reyes National Seashore Association (PRNSA) implemented an approximately 613-acre wetland restoration project in the southern end of Tomales Bay in Marin County, California. The project principally focused on conversion of a former dairy ranch into tidal wetlands, as this area was once historically. However, rather than try to recreate historic conditions, the Park Service focused on restoring natural hydrologic tidal and freshwater processes, thereby promoting restoration of hydrologic and ecological functions. Natural hydrologic processes are the cornerstone of many hydrologic and ecological functions and economic “services” associated with wetlands. Perhaps, one of the most important functions that wetlands can play -- particularly in Tomales Bay -- is water quality improvement. While it is generally perceived as pristine, this rural coastal watershed still suffers from negative anthropogenic influences such as agriculture, home and road development, leaking septic systems, mercury mining, landfills, and oil spills. During the last few decades, poor water quality in the Bay has forced oyster fisheries to close down several times and, in 1998, was associated with a virus outbreak.

Restoration began in 2006. From 2000 (date of sale of land to Park Service) to 2006, the Giacominis continued to operate a full-scale dairy operation under a Reservation of Use Agreement. There were at least three dairy herds, and the ranch was actively maintained through manure spreading, haying, and flood and spray irrigation of certain pastures in the summer. This period is referred to in data analyses as Pre-Restoration as it pre-dates any restoration efforts. In 2006, the Giacominis sold the dairy string and instead grazed a much smaller herd of dairy heifers. Maintenance activities were also scaled back, with reduced haying, manure spreading, and irrigation of pastures during the summer. Because most of the restoration achieved during this period probably resulted from passive measures such as discontinuation or scaling back of active dairying and ranch management, the 2006-2008 period is referred to as Passive Restoration, because removal of agricultural management potentially could have led to some improvement or “restoration” of water quality conditions within the ranch, even without active restoration.

In 2007, the first phase of active restoration of the Giacomini Ranch was implemented. However, as most of this restoration focused on removal of dairy barns and other infrastructure and agricultural conditions and did not substantially alter hydrologic conditions, the ecological changes arising from this phase were comparatively small. The second and more intensive phase of restoration commenced in July 2008 and was completed with the final levee breach in October 2008. This phase involved full-scale levee removal, construction of new tidal channels, realignment of leveed channels, and removal of drainage ditches, although, due to the need to maintain dry working conditions, final hydrologic reconnection with Lagunitas Creek and other streams did not occur until the final levee breach in late October 2008. In addition, some hydrologic improvements occurred in the adjacent Olema Marsh, with lowering of a small berm that constrained outflow of this system to Lagunitas Creek.

As an integral component of the restoration project, the Park Service has implemented a comprehensive long-term monitoring program to assess whether restoration is successful. This program assessed conditions before and after restoration within the Project Area (Giacomini, Olema Marsh) and even several natural marshes in Tomales Bay and other local watersheds. A key component of this monitoring program has been water quality monitoring, which has included monthly to quarterly systematic sampling of water quality field parameters within these Study Areas. Parameters include nutrients (nitrate, nitrites, total ammonia, total phosphorous, total dissolved phosphates or dissolved orthophosphates), and pathogen indicators (total and fecal coliform). This technical memorandum summarizes changes in water quality conditions within the Project Area during the fourth year after restoration for Water Year (WY) 2012.

Some improvement in water quality conditions were expected immediately following restoration due to decreases in residence time for leveed waters. However, these improvements were expected to be tempered to a large degree initially by pulses in sediment and nutrients from re-working of exposed soils by tides, floods, and decomposition and mineralization of pasture vegetation, with variables such as pH and dissolved oxygen (D.O.) responding accordingly to the resulting flux in nutrients.

Over the long term, water quality conditions were expected to improve not only in the Project Area, but potentially within the watershed itself. More than 66 percent of the inflow to Tomales Bay comes from the Lagunitas Creek watershed (Fischer and Smith 1996), and the creek flows directly through the Project Area. Previously, levees funneled flood flows and associated pollutant discharge directly to Tomales Bay, but with removal of the levees, the creek is now reconnected to its historic floodplain. Therefore, this restoration project could have watershed-scale benefits to water quality and to the flora and fauna that inhabit the estuary.

Summary of Monitoring Approach

This technical memorandum summarizes changes in water quality conditions within the Project Area during the fourth year after restoration for WY 2012. Water quality conditions in the Project Area during the first three years after restoration and prior to restoration were summarized in four previous reports (Parsons 2009; Parsons 2010; Parsons 2011; Parsons 2012a).

As an integral component of the restoration project, the Park Service has implemented a comprehensive long-term monitoring program to assess whether restoration is successful. To facilitate analysis of restoration progress, the Long-Term Monitoring Program relies on a modified BACI ("Before-After, Control-Impact") sampling framework. The Giacomini Wetlands and another restoration site, Olema Marsh, represent the Impact Area, while Reference or Control Areas were established in natural tidal marshes in Tomales Bay and adjacent watersheds to facilitate a comparative evaluation of changes in the restored system relative to ambient conditions. In addition, sampling was also conducted on the upstream perimeter of the Project Area (Upstream Areas) to more clearly understand the quality of waters flowing into the Project Area. The Project Area were further divided for sampling design purposes into sampling units based on physical location and/or hydrologic differences, including Giacomini-East Pasture (EP), Giacomini-West Pasture (WP), Lagunitas Creek (LAG), leveed portion of Tomasini Creek (TOM), Olema Marsh (OM). Lagunitas Creek divides the Giacomini Wetlands into two pastures or areas – East and West Pastures. Reference Areas included the Undiked Marsh (UM) directly north of Giacomini, Walker Creek Marsh (WCM) in Tomales Bay, and Limantour Marsh (LIM) in Estero de Limantour,

Monitoring of these areas occurred both four- to five years before and four years after restoration, as well as two years in between these periods when cows were removed, but levees were still present (Passive Restoration).

A complete description of the water quality sampling methodology is available in the pre-restoration monitoring report (Parsons 2009). In general, monitoring of water quality has occurred on a quarterly basis, although, during the first few years, field parameters were measured on a monthly basis. Subsequent analysis of the data suggested that sampling effort could be reduced to quarterly without losing the power to detect differences in or changes in the system. Towards the end of the pre-restoration period, efforts were made to sample during one to two storm events per year, although prior sampling events sometimes accidentally captured storm events.

Since the wetlands were restored, the sampling schedule has been as follows: seven (7) scheduled and storm sampling events conducted in Year 1 (2008-2009); five scheduled/storm sampling events conducted in Year 2 (2009-2010); six (6) scheduled and storm sampling events conducted in Year 3 (2010-2011); and four scheduled events in Year 4 (2011-2012). Timing and scale of monitoring efforts during Years 1 and 4 were constrained by funding issues. Sampling events in Year 4, which occurred in Water Year (WY) 2012, were conducted in October 2011, November 2011, January 2012, April 2012, and July 2012.

The water quality monitoring program assesses the following variables: salinity (ppt), temperature (degrees Centigrade), dissolved oxygen (mg/L and %), pH, conductivity and specific conductance (*u* and mM), nitrates (NO3-; mg/L), nitrites (NO2-;mg/L), total ammonia (NH4+/# of >MDL detections), dissolved ammonia (NH4+/mg/L), total dissolved and orthophosphates (PO4-/mg/L), total phosphorous (P/# of >MDL detections), fecal coliform (mpn/100ml), chlorophyll a (mg/L), phaeophytin (mg/L), and dissolved organic carbon (DOC; mg/L). Also, loading rates of nitrates and fecal coliform are also calculated using instantaneous measurements of streamflow or stream gage data, as well as channel width and depth information: these results are presented as mg/seconds (nitrates) and mpn/seconds (fecal coliform). This report only addresses results of some of these variables, including salinity (ppt), temperature (degrees Centigrade), dissolved oxygen (mg/L), pH, nitrates (NO3-; mg/L), total ammonia (NH4+/# of >MDL detections), dissolved ammonia (NH4+/mg/L), total dissolved and orthophosphates (PO4-/mg/L), total phosphorous (P/# of >MDL detections), fecal coliform (mpn/100ml), and nitrate and fecal coliform loading.

In general, sampling methodology has remained consistent with pre-restoration techniques with a few exceptions. Some of the notable changes in sampling since 2006 involve more storm sampling; use of a different laboratory for scheduled nutrient sampling events resulting in a shift in some of the types and detection limits of nutrients being analyzed; and changes in sampling locations when restoration eliminated some stations, and tidal channel creation created opportunities for new stations, particularly in the East Pasture.

Whenever possible, original sampling stations were retained, with some simply renamed to reflect changed status after restoration. One other change is that one station (EUC1) was switched from being a Project Area (PA) to an Upstream (US) site, because waters in this area now derive entirely from downslope run-off and groundwater inflow and, therefore, more accurately reflect the quality of water flowing into the Project Area from the surrounding urban watershed than Project Area conditions. As the change occurred after restoration, the Year 1 data has been reanalyzed to account for this change in status. Therefore, values for Year 1 in this report may differ slightly from those in the Year 1 report (Parsons 2010).

Starting in November 2007, analysis of nutrient samples was largely switched to a different university laboratory that offered lower MDLs and the ability to detect nutrients at very low concentrations. Because of this switch, analysis of total dissolved phosphates were replaced by dissolved orthophosphates, which are not synonymous, as total dissolved phosphates includes phosphates that are not orthophosphates or biologically reactive phosphates. In addition, total phosphorous was later added to the analytes list, so there is no comparative pre-restoration data for this constituent: inclusion of this parameter was intended to determine how much of the phosphorous within the system is in particulate rather than dissolved form. Because of funding constraints, total phosphorous was only monitored during a few events in Year 4.

Water quality data, including nitrates, ammonia, phosphorous, and fecal coliform, can often include “non-detects” or data that falls below the method detection limit (MDL) or practical quantitation limit (PQL). Most of the field parameter data fell within instrument detection limits. For these parameters, a statistical package (Minitab; State College, PA) was used to statistically analyze data using traditional either parametric or non-parametric techniques. Assumptions of parametric statistics (homogeneity of variance; normality) were checked both graphically by reviewing residual vs. fit plots, normality plots, and histogram of residuals and by using other means such as a comparison of standard deviation ratios between groups. Some preliminary assessments of possible temporal autocorrelation between sampling dates for specific sites and variables were performed using the ACF (Autocorrelation Function) analysis program in the R software package: any autocorrelation for these selected sites and variables appeared minimal. Some data were transformed in order to better meet assumptions, however, in general, datasets are large enough for the Central Limit Theorem to be applicable regarding normality of residuals. For data that did not meet assumptions even with transformations, non-parametric procedures were used if the distributions of the groups being tested appeared roughtly equivalent. The Mood Median test was used rather than Kruskal-Wallis, because, according to Minitab, while the Kruskall-Wallis test may be more powerful in terms of detecting change, the Mood Median test is more robust towards outliers, and there are many valid outliers in this data set.

For censored data with non-detect values, substitution with the limit can be employed if the number of non-detects or “censored” data is relatively low (<15% of the data; Helsel 2006, *pers. comm. in* Parsons 2009.). However, when the number of non-detects exceeds approximately 15% of the data, more sophisticated analytical techniques should be used that take advantage of the information provided even if values fall below (or even above) MDL (Helsel 2005). Most of the nutrient and pathogen data showed varying proportions of non-detect data, particularly prior to restoration with use of the commercial rather than academic laboratory, with some of the most problematic in terms of high numbers of non-detect values being the total ammonia, total phosphorous, and (early on) total dissolved phosphates. For parameters that had moderate to large number of values that fell either below or above the reporting limit, summary statistics were calculated using statistical methodologies commonly employed in other fields such as the medical and biotechnology industries that fit a distribution to observed values using Maximum Likelihood Estimates (MLE), Kaplan-Meier Survival Analysis, or other parametric or non-parametric equivalents and then extrapolate a collection of values above and below the reporting limit for use in estimations (Helsel 2005).

Changes Following Restoration – Year Four: Results and Discussion

Changes in Climatic Patterns

As noted earlier, five (5) scheduled or storm sampling events occurred in Year 4 or WY 2012. In general, WY 2012 (October 2011 – September 2012) was a drier year (33.3 inches) than the previous WY, 2011 (October 2010 – September 2011; 53.7 inches; Western Regional Climate Center, Olema Valley, Figure 1). WY 2012 differed from WY 2011 not only in the volume of rainfall, but in the distribution of rainfall, with rainfall events in WY 2012 being mainly concentrated towards the end of the season following a fairly dry winter, while rainfall events in WY11 showed two distinct peaks in fall and mid-winter (Figure 1). The U.S. Geological Survey stream discharge data for the Point Reyes Station depicts this unusual pattern for WY 12 by lower than median flows during the winter, but higher than median flows starting in March 2012 and extending into May 2012: Higher flows during the summer relative to the 37-year median may more reflect changes in regulatory minimum streamflow requirements starting in the late 1990s than climatic conditions (Figure 2).

The first year after restoration was actually slightly drier than average (31.5 inches; Western Regional Climate Center, Olema Valley), but the driest year during the monitoring period actually occurred in the early years of monitoring, while the dairy was still in operation (WY 2004: 22.29 inches; NPS; Bear Valley). In contrast, Year 2 or WY 10 was quite wet, with rainfall totaling 47.6 inches (Western Regional Climate Center, Olema Valley). During that year, rainfall volume remained relatively elevated between November and May, with another peak in January 2010. While levee removal during restoration in 2008 resulted in lowering of creek “bank” elevations to that sufficient to allow overflow of a 2-year-flood event, no overbank flooding from storm flows occurred during either WY 2009 or 2010, even with higher rainfall levels in 2010. In WY 2011, at least one overbank flooding event occurred. There were no overbank flooding events in WY 2012.

Overall, a comparison of average differences during pre- and post-restoration sampling periods showed that the post-restoration period (fall 2008 to fall 2012) was, on average, slightly wetter than most of the pre-restoration period (fall 2004 to fall 2008), although both sampling periods had, on average, higher than normal rainfall, ranging from 0.70 inches above normal (pre-Restoration) to 3.51 inches above normal (post-restoration). In addition, a visual examination of the monthly precipitation chart suggests that, even if annual totals were similar, there may have been differences in monthly distribution, with post-restoration distribution patterns more evenly distributed, at least in Years 2 and 3 (Figure 1).

Changes in Hydrologic Conditions in Project Area

Water quality conditions within the Project Area are strongly swayed by – and tied to – changes in hydrology. One of the most dramatic changes in the Giacomini Wetlands after restoration was the sweeping expanse of water that spread almost immediately across the former dairy pastures with the twice-daily flooding of the tides. This change was predicted. However, what was less well understood was the process by which hydrology within the restored Ranch would evolve, similar to that of vegetation.

During planning for the restoration project, computer hydraulic modeling conducted as part of planning for the restoration project estimated that, based on existing and proposed elevations, 256 of the 550 acres in the East (area adjacent to Point Reyes Station) and West (area adjacent to Inverness Park) Pastures of the Giacomini Ranch would be inundated by tides daily or close to daily (KHE 2006). This modeling assumed that no levees would remain and that some tidal channels would be created. Larger tidal channels were built to jump-start marsh evolution, but only a few smaller tidal creek channels were constructed, with the assumption that most of the smaller channels would develop naturally over time. While levees were removed, the undiked marsh that had developed on the outboard of the levees was, in many cases, higher in elevation than the marshplains or former pastures. These marsh shelves, then, represent mini "levees" that can direct – or even constrain – flow within the former pastures.

Hydrologic changes were not notable after final removal of the West Pasture levees and completion of preliminary restoration activities in Olema Marsh in mid-October 2008 (KHE 2009a). However, very dramatic changes occurred almost immediately after final removal of the East Pasture levees on October 25, 2008 (KHE 2009a). Within days, much of the East Pasture -- and the very southern portion of the West Pasture -- was seemingly permanently flooded.

Based on data collected during continuous hydrologic monitoring by KHE, water levels at the very northern end of the Project Area in Lagunitas Creek (former North Levee) immediately showed compression in the maximum and minimum water levels during spring tides – that is, the low tides were not getting as low as they did previously during the lowest low tide conditions (KHE 2009a). Because channel width and density was not large enough currently to fully accommodate flows, waters were not fully draining on the low tide, leaving a significant amount of water in East Pasture channels and marshplains even on the lowest low tides. Drainage problems were exacerbated by the fact that the outboard marsh shelves, which functioned as mini-levees, were funneling flows exclusively through the two primary tidal channel outlets that were created—the Tomasini Slough, which flows into Lagunitas Creek near Railroad Point in the northern portion of the East Pasture, and, to a lesser extent, the new side channel for Lagunitas Creek, which drains the new Marshplain Enhancement area in the southwestern portion of the East Pasture.

Immediately after restoration, mapping of the permanently flooded areas during extreme low tide conditions indicated that water levels were not dropping below 4 ft NAVD88 in the East Pasture and approximately 3.75 ft -<4 ft NAVD88 in the West Pasture (NPS, unpub. data). Water level patterns in Lagunitas Creek were also affected: a flattening of the water level curve below 3.5 feet suggested that water levels in the creek were also dropping more slowly because of the added volume of water being conveyed by the marshplain (KHE 2009a). Prior to restoration, the morphology of gravel bars in Lagunitas and Fish Hatchery Creeks suggested that subtidal conditions after restoration would persist below 2.0 ft NAVD88 in Lagunitas Creek and the East Pasture and 3.4 ft NAVD88 in the West Pasture due to the weir-type effect these bars have on channel water levels (KHE 2006). In addition to changes on water level patterns, restoration also affected timing of tides, resulting in delays of low tides relative to predicted conditions at the nearby Inverness tide station by as much as 2 hours or more (NPS, unpub. data).

These dramatic hydrologic changes were most evident after restoration in the amount of subtidal area or areas that remained permanently inundated. Based on hydraulic modeling, subtidal extent, particularly in the East Pasture, was much greater after the levees were breached than expected under fully evolved conditions (Figure 3). In the East Pasture, subtidal area under extreme low tide conditions (-1.7 ft to -0.4 ft MLLW or -1.2 ft to +0.1 ft NAVD88) totaled 109.4 acres immediately after restoration, compared to the 26.5 acres of subtidal area predicted under fully evolved conditions (NPS, unpub. data; KHE 2006; Figure 3). The discrepancy between restored and fully evolved conditions was not quite so great in the West Pasture, where subtidal extent predicted under fully evolved conditions (2.2 acres; KHE 2006) was only slightly lower than actual (7.4 acres; NPS, unpub. data; Figure 3). Interestingly, subtidal extent was actually lower under neap tide conditions – when the difference in elevation between low and high tides is substantially compressed – than under spring tide conditions, when low tides reach some of their lowest levels. In December 2009, subtidal areas totaled 52.9 acres in the East Pasture and 4.5 acres in the West Pasture when tides ranged between 1.9- to 2.7 feet MLLW (1.4- to 2.2 ft NAVD88). This represents almost a 51 % reduction in subtidal area with only a 1- to at most 3-

foot difference in tidal water elevation. These results suggested that drainage was being constrained by the larger volume of water that flowed into the newly restored wetland on a spring tide, when high tides are very high, than on a neap tide, when high tides are lower.

Circulation and drainage patterns are expected to be further altered in the future by changes in Lagunitas Creek (and interior tidal channel) geometry. Immediate post-project surveys had indicated a uniform increase (1.0 ft) in bed elevation of the mainstem Lagunitas Creek channel immediately upstream of the former cattle crossing near White House Pool in 2009 relative to elevations in 2003 (KHE 2009b). In contrast, channel elevations immediately upstream of the former North Levee area remained fairly comparable in 2009 to those measured in 2003 by the USGS (KHE 2009b). Since restoration, elevations within the Lagunitas Creek cross-sections have not changed appreciably, with the exceptions of shoals at channel outlets (KHE 2011a). In 2009, ebb shoals or gravel bars developed at the mouth or downstream of the mouth of the newly constructed channels draining the East Pasture, with accretion during the first year totaling more than 1 to 2 feet (KHE 2009b). These deltaic-type shoals had encroached into the mainstem Lagunitas Creek channel, reducing the cross-sectional flow area, although they did not span the full width of the channel (KHE 2009b). While both of these shoals rapidly formed after restoration, their evolutionary paths have diverged somewhat. The horseshoe-shaped Tomasini Slough outlet shoal has remained relatively consistent in elevation between 2010 and 2011. It is comprised of an inner and outer shoal that range in elevation from 1- to 2 feet NAVD88 (KHE 2011a). Conversely, the shoal at the mouth of the new side channel off Lagunitas Creek has continued to accrete or build in elevation with estimated deposition rates of 0.7 feet in WY 2010 and 0.75 feet in WY 2011 (KHE 2011a). With post-restoration winters being relatively dry, little energy in the way of flood scour has been available to counteract deposition of sediments at the mouth of new tributaries to Lagunitas Creek, therefore leading to a net depositional environment. Should flood flows continue to be reduced, shoals will continue to build in Lagunitas Creek and perhaps change circulation and drainage patterns in the creek and wetland.

While elevations may have increased at the mouth, both of the newly constructed channels had actually deepened since restoration was completed. By 2010, the downstream portions of Tomasini Slough had decreased in elevation relative to constructed elevations by as much as 1.8 feet, with an additional drop of 0.75 feet during the next year (KHE 2011a). The one upstream station with historic data showed little elevation chance since pre-restoration conditions (KHE 2011a). A similar pattern of channel incision occurred at the newly created side channel off Lagunitas Creek in the East Pasture. At least 1 foot of both channel deepening and widening took place in downstream portions of this small tidal creek, while upstream portions widened, but actually became more shallow through deposition of approximately 1 foot of sediment (KHE 2011a). Unconstructed channels are also becoming deeper: these are naturally developing channels on the marsh floodplain. Unfortunately, the lack of vegetation, particularly in the northern portion of the East Pasture, may slow down this process somewhat by encouraging overflow of tidal waters and floodwaters onto the marshplain rather than keeping them in channels (KHE 2010a).

Interestingly, marshplain areas appear to be gaining in elevation in both the East and West Pastures, despite the massive vegetation die-off in the East Pasture that would be expected to compact soils due to loss of root volume below the soil surface (Parsons and Ryan, *in prep*.). In both pastures, elevation gains between 2008 and 2010 ranged from 13.5 mm in the West Pasture to 19.2 mm in the East Pasture, with sediment deposition rates for that period as measured by feldspar markers ranging between 5.5 mm in the West Pasture and 8.1 mm in the East Pasture (Parsons and Ryan, *in prep*.). In 2011, the trends in elevation shifted somewhat, with elevation again increasing in the West Pasture (4.5 mm) relative to 2010 elevations, but decreasing in the East Pasture (-10.2 mm), although, overall, elevations were still higher post-restoration than pre-restoration (Parsons and Ryan, *in prep*.). Interestingly, one sampling site at the western end of Walker Creek Marsh in the northern end of Tomales Bay that had not appeared to gain in elevation since 2008 such had positive elevation increases in 2011 (4.5 mm; Parsons and Ryan, *in prep*.). Considering that elevation gains typically exceed sediment deposition rates, most of the elevation gains in the restored wetlands appear to result from changes in subsurface processes, with reintroduction of tides potentially increasing porewater volume in the soils and slowing down subsurface oxidation rates of organic matter (Parsons and Ryan, *in prep*.).

Most of the sediment deposition occurring in Lagunitas Creek and the Project Area appears to come from re-working of soils from the Project Area, which are now exposed and vulnerable after construction and decay of pasture vegetation. With the first winter being a dry one, sediment inputs from the upper watershed were probably minimal, particularly as there were no overbank flooding events. While the Year 2 winter was much wetter, there was still not enough flow volume during storm events to cause overtopping of creek banks in the Project Area, and, thereby, any deposition of sediment on newly restored marshplains. Some overtopping did occur during the winter of Year 3, when rainfall totals were even higher than Year 2, but there was only one very brief event. Even during large storms, most of the peak flood flow and sediment generated are trapped by upstream dams, reducing flood volume and sediment loading to downstream areas. Despite this lack of overbank flooding, sedimentation monitoring has shown that sediment was still deposited on Project Area marshplains during the last three years (Parsons and Ryan, *in prep*.). Dry winters and reduced flood flow volume have led to a net depositional environment both within the Project Area and other marshes, except where flow velocity is high enough to counteract this trend, such as in the downstream portions of the Tomasini Slough and the Lagunitas Creek side channel. With overbanking flooding during storms being minimal, much of this sedimentation may derive from re-working of Project Area soils (Parsons and Ryan, *in prep*.).

Annual deposition rates since restoration appeared higher in the northern portion of the East and West Pastures than in other sites in Tomales Bay and lower than in Limantour Estero, however, differences were not statistically significant (GLM, df=2, F=1.67, P=0.199; Parsons and Ryan, *in prep*.). Average annual sedimentation rates since restoration in the Giacomini Wetlands have ranged from 1.7 to 3.5 mm/year, compared to 0.5 to 2.6 mm/year in other Tomales Bay sites (Parsons and Ryan, *in prep*.). The lower elevation, more deeply subsided East Pasture area in the Giacomini Wetlands appeared to have a higher average annual sedimentation rate (3.5 mm/year) than the higher elevation West Pasture area (1.7 mm/year; Parsons and Ryan, *in prep*.). Median annual sedimentation rates appeared slightly lower, at least for Giacomini: 1.8 mm/year (West Pasture) to 2.5 mm/year (East Pasture), compared to 0.7 to 2.7 mm/year in other Tomales Bay sites (Parsons and Ryan, *in prep*.). However, again, differences were not statistically significant (Mood Median Test, df=2, Chi-Square=0.92, P=0.69). The Limantour sites had a higher range of annual sediment deposition rates than Tomales Bay, with average rates ranging from 1.5 to 3.9 mm/year and median rates ranging from 1.1 to 4.0 mm/year (Parsons and Ryan, *in prep*.). These numbers are still seemingly lower than historic sediment deposition rates in Tomales Bay, which were estimated to average 5 mm/year (Rooney and Smith 1999). In San Francisco Bay, current short-term accretion rates appear to range between 3.1 and 5.9 mm/year, with higher rates at lower-elevation marshes (Callaway et al. 2012).

Essentially, the Giacomini Wetlands are in the process of hydrologic evolution. The conditions predicted by hydraulic modeling represent a later phase in wetland development. Over the coming years, existing and created channels will continue to increase in size to accommodate flood flows, and new tidal channels will develop, increasing exchange between the restored wetland and Lagunitas Creek and creating more of an equilibrium between tidal inflow and outflow. In addition, some portions of the higher elevation undiked marsh outboard of the levees may continue to erode (as they have been doing prior to restoration), allowing more tidal waters to sheetflow across the marshplain back into Lagunitas Creek. Some of these changes may be accelerated during flood events, although storms so far have not been of sufficient magnitude to dramatically alter the wetland landscape.

This evolution appears to be already well underway. Hydrologic data suggested that the marsh was draining slightly faster during outgoing or ebb flows in 2009 than 2008 (KHE 2010a), and drainage improved slightly again between 2009 and 2011, at least during spring tides (KHE

2011b). Low tide elevations continue to be constrained as they were prior to restoration by the presence of gravel and sand bars at the mouths of creeks, which keep water levels at about 2.0 feet NAVD88 (KHE 2011b).

This improvement in drainage efficiency can be seen in the dramatic declines over the last few years in the extent of subtidal areas during an extreme low tide. Acreage declined from 109.4 acres in the East Pasture immediately after restoration to 68.1 acres in summer 2010 under approximately equivalent tide conditions (-0.44 to -1.74 ft MLLW in 2008 vs. -1.54 to -1.67 ft MLLW in 2010, Figure 3). This represents a 38% decrease in extent of permanent inundation during extreme low tides within two years. In 2011, this trend appeared to continue (Figure 3): acreage of subtidal areas in the East Pasture dropped to 51.0 acres, even though water levels may have been influenced somewhat by the unusual rainfall pattern in WY 2011, where precipitation extended well into the summer. (Summer stream discharge flows averaged 10 cfs compared to the median estimate of 6 cfs, which may have kept the marsh from fully draining during low tide events.) This situation demonstrates that ecosystem evolution following restoration is not a linear process, but can occur in distinct stages or phases that involve triggering or exceeding thresholds before the wetland moves into the next evolutionary stage or phase.

Changes in General Water Quality Conditions in Project Area

Salinity

The Project Area lies in the Estuarine Transition Zone, the dynamic interface between freshwater and saltwater influences. For this reason, salinity regimes and patterns are understandably dynamic both spatially and temporally. Much of the freshwater inflow comes from the copious amount of small freshwater drainages and emergent groundwater flow from the Point Reyes Mesa and Inverness Ridge, as well as the larger creeks such as Lagunitas Creek, Olema Creek, Bear Valley Creek, Fish Hatchery Creek, and Tomasini Creek.

Because of these freshwater influences, prior to restoration, salinities and temperatures differed significantly between the Project Area and other Study Areas (Parsons 2009). Salinity averaged 6.9 parts per thousand (ppt) in the Project Area, 22.0 ppt in Reference Areas, and 0.6 ppt in Upstream Areas, which receive less or no tidal influence and have strong perennial or seasonal freshwater influences (Kruskal-Wallis, n=1261, df=2, H=472.6, P < 0.001; ibid).

Based on statistical analyses, a significant change in average salinities occurred within the Project Area after restoration. Average salinities seemingly climbed 70% from 6.9 ± 0.3 (S.E.) ppt Pre-Restoration to 8.5 (± 0.9; S.E.) ppt during Passive Restoration and to 11.7 ± 0.5 (S.E.) ppt after restoration (GLM, df=2, F=41.9, P<0.0001; sqrt transformed for analysis): post-restoration salinities differed significantly from pre- (PP<0.0001) and passive- (P=0.0008) restoration salinities, which showed only a weakly significant difference from each other (P=0.10). Median salinities followed a similar pattern, climbing from 1. 6 ppt during Pre-Restoration and 4.2 ppt during Passive Restoration to 10.8 ppt during Full Restoration (Mood Median Test, df=2, Chi-Square=86.6, P<0.0001). Median salinities jumped during the first year after restoration (16.6), but dropped during Year 2 (4.3 ppt), climbing slightly back up in Year 3 (8.7 ppt) and even higher in Year 4 (10.4 ppt). Average salinities appeared to be slightly higher than medians, suggesting that either some higher salinity sampling events (e.g., summer) or areas influenced salinity conditions: a strong disparity existed between average and median salinities in Year 2. Salinities averaged 17.1 ± 1.2 (S.E.) ppt in Year 1, dropping to 10.6 ± 1.0 (S.E.) in Year 2; 9.43 ± 0.7 (S.E.) ppt in Year 3, and 10.7 (± 0.8; S.E.) in Year 4. Figure 4 shows changes in salinities for each of the sub-sampling units or areas within the Project Area.

Water quality monitoring conducted by Kamman Hydrology & Engineering pre- and post-levee removal showed that salinities increased not only within the former pastures, but within Lagunitas

Creek, as well. Average salinity in Lagunitas Creek increased immediately after final removal of the East Pasture levees on October 25, 2008, although the West Pasture levee removal and Olema Marsh restoration components completed two weeks earlier appeared to have no immediate discernible effect on Lagunitas Creek salinity (KHE 2009a). In general, average salinity, if not maximum salinity, increased along the entire portion of Lagunitas Creek within and upstream of the Project Area, although salinity levels and the absolute magnitude of the change decreased with distance upstream from the downstream boundary of the Project Area (KHE 2009a). At this furthest downstream location (former North Levee), the maximum salinity remained the same immediately post-restoration, but average salinity increased, because there was an upward shift in the lower limit of salinity, with the range increasing from between 10 and 32 practical salinity units (psu; psu~=ppt) immediately pre-restoration to between 18 and 34 psu immediately after restoration (KHE 2009a). While the range of salinity variations in 2009 remained comparable to immediate post-levee breach conditions in 2008, the amplitude in salinities was more compressed in 2009, ranging only from approximately 22 to 35 psu (KHE 2010a).

Salinities increased in the Project Area primarily in response to the reintroduction of tidal action. However, results definitely reflect the strong influence of intra-annual and inter-annual climatic patterns. In 2008-2009 (WY 2009), the dry weather and unusual precipitation patterns led to a much higher average salinity in the Project Area (17.1 ppt) than in 2009-2010 (WY 2010; 10.6 ppt) and 2010-2011 (WY 2011; 9.4 ppt), when rainfall was higher and somewhat more evenly distributed, or in 2011-2012 (WY 2012; 10.7 ppt), when a wet spring followed a relatively dry winter. In comparison, average salinities prior to restoration were only slightly lower (6.9 ppt) than these more recent post-restoration salinities.

The strong influence of dry weather during the first year of restoration can be seen in a similar pattern of salinity changes within Reference Areas. For the four-year period prior to restoration, the median salinity within Reference Areas was 25.5 ppt. Median salinities in Reference Areas actually decreased 24% between Pre-Restoration and Passive Restoration (median=19.3 ppt) sampling periods, but, in Year 1 following restoration (2008-2009), they climbed 20% to 30.7 ppt (Mood Median Test, df=4, Chi Square=35.0, P<0.0001). In the four years since restoration, median salinities in Reference Areas have remained roughly similar to Passive Restoration (Mood Median Test, df=2, Chi-Square=0.018). In Year 2, salinities in Reference Areas dropped back down to a median of 21.0 ppt and, in Years 3 and 4, dropped even further to medians of 18.7 ppt and 18.4 ppt, respectively. Average salinities in Reference Areas during these sampling periods were 22.0 ± 0.7 (S.E.) ppt (Pre-Restoration); 20.4 ± 1.2 (S.E.) ppt (Passive Restoration); 29.3 ± 1.0 (S.E.) ppt (Year 1-Full Restoration); 19.1 ± 1.5 (S.E.) ppt (Year 2-Full Restoration); 17.6 ± 1.2 (S.E.) ppt (Year 3-Full Restoration); and 17.1 ± 1.0 (S.E.) ppt (Year 4-Full Restoration).

While one of the Reference Areas is adjacent to the Project Area and could have been affected by changes in tidal prism and salinity dynamics in the southern portion of the watershed, the other Reference Areas sampled following restoration are either at the opposite end of the estuary near the estuary's mouth or in a completely different watershed and were unlikely to have been substantially affected by restoration activities.

Because freshwater more strongly influences the Giacomini Wetlands even after restoration due to the numerous creeks, drainages, and groundwater inflow, salinities within the Project Area are not expected to totally converge with those of Reference Areas, although simultaneously tracking salinity patterns in Reference Areas provide valuable information on whether changes observed in the restored marsh are due more to climatic patterns or the effects of restoration.

Temperature

The influence of freshwater was also evident in water temperatures prior to restoration (Parsons 2009). Before levees were breached, temperatures were lower in the Project Area (median = 15.1 degrees Centigrade) than in Reference Areas (median=17.3 degrees Centigrade), although not lower than those in Upstream Areas (median=12.7 degrees Centigrade; Kruskal-Wallis, df=2, H=50.04, p<0.001). While diking of the Giacomini Ranch and the culvert-levee road system at Olema Marsh resulted in longer residency time for waters – and more time for sunlight to drive up water temperature – the substantial freshwater influences from both creek and emergent groundwater flow appeared to moderate the effect of these management impacts on water temperature.

With removal of the levees and reconnection of Project Area waters to Lagunitas and Tomasini Creeks, median temperatures dropped by 6% within the Project Area from 15.1 degrees Centigrade Pre-Restoration to 14.2 degrees Centigrade during Passive Restoration and 14.1 degrees Centigrade during Full Restoration (Mood Median Test, df=2, Chi-Square=8.84, P=0.012; Figure 5). During Full Restoration, median temperatures varied widely from a high of 15.4 degrees Centigrade in Year 1 to a low of 12.9 degrees Centigrade in Year 2, with Year 3 and Year 4 falling in-between (14.2 and 14.5 degrees Centigrade, respectively). Average temperatures also differed between restoration periods (GLM, df=2, F=9.54, P<0.0001; log-transformed for analysis), with all periods either significantly or weakly significantly different from each other (P<0.09; Figure 5). Decline in mean temperature was more subtle than that of the medians, with temperatures dropping from 15.9 ± 0.2 (S.E.) degrees Centigrade before the levees were breached to 14.2 ± 0.5 (S.E.) degrees Centigrade during Passive Restoration and 15.2 (± 0.2 (S.E.) degrees Centigrade after levees were breached. Average temperatures appeared slightly higher most years than median ones, ranging from 13.6 ± 0.3 (S.E.) degrees Centigrade in Year 2 to 16.6 ± 0.5 (S.E.) degrees Centigrade in Year 1. Temperatures in Years 3 and 4 within the restored wetland averaged 15.1 ± 0.5 (S.E.) and 15.6 ± 0.5 (S.E.) degrees Centigrade respectively

Interestingly, mean temperatures in Reference Areas also decreased after “restoration,” although most of these areas could not have been directly influenced by the project. Average temperatures dropped approximately 11% from 17.2 ± 0.3 (S.E.) degrees Centigrade Pre-Restoration to 15.7 ± 0.5 (S.E.) degrees Centigrade during Passive Restoration and 15.4 ± 0.3 (S.E.) degrees Centigrade during Full Restoration (GLM, df=2, F=10.43, P<0.0001). Temperatures averaged 16.1 ± 0.7 (S.E.) degrees Centigrade during Year 1, 14.4 ± 0.5 (S.E.) degrees Centigrade during Year 2, 15.5 ± 0.7 (S.E.) degrees Centigrade during Year 3, and 15.7 ± 0.6 (S.E.) degrees Centigrade during Year 4 of the Full Restoration period. Median temperatures differed significantly between treatment years, decreasing 20% from 17.3 degrees Centigrade during Pre-Restoration to 14.8 degrees Centigrade during Passive Restoration and 13.8 degrees Centigrade during Full Restoration (Mood Median, df=2, Chi-Square=12.21, P=0.012).

In general, then, trends within the Reference Areas appeared to parallel those of the Project Area, even if the Project Area would be expected to have slightly different patterns in temperature due to restoration-related changes. Temperatures declined during throughout the monitoring period, although temperatures climbed slightly during Year 1 post-restoration (GLM, df=1 F=15.53, P<0.0001; log transformed for analysis). Higher rainfall – and more freshwater inflow from watershed sources – may have led to colder water temperatures in both the Project and Reference Areas during the later part of the monitoring period, except for Year 1.

Prior to restoration, Reference Areas exceeded the lethal limit for salmonids of 25 degrees Centigrade (Moyle 2002) approximately 6.7% of the time, and another 17.8% exceeded 22 degrees Centigrade, the suboptimal limit for salmonids (Moyle 2002, Parsons 2009). Comparatively, in the Project Area, before the levees were breached, temperatures exceeded the lethal limit during only 5% of the sampling periods and exceeded the suboptimal limit during approximately 15 % of the sampling periods.

In the first year of Full Restoration, temperature exceedance levels in the Project Area actually dropped despite the low rainfall, with temperatures exceeding 25 degrees Centigrade reduced slightly to 4.4% of the sampling events, although the number of exceedances of the suboptimal limit remained the same (15.0%). This compared to a slight drop for Reference Areas in Year 1 to exceeding the lethal limit only 3.3 % of the sampling periods and the suboptimal limit of 22 degrees only 14.9% of the events. In Year 4, the restored wetlands exceeded the lethal limit during approximately 5% of the sampling events and the sub-optimal during approximately 13% of the sampling events, down from 8% and 17%, respectively the year prior. These numbers compare to 7% and 15%, respectively, in Year 4 and 14% and 17%, respectively, in Year 3 in the Reference Areas.

One of the objectives of the restoration project involves the marsh eventually evolving towards conditions similar to those present in reference natural marshes, specifically for those parameters where, based on site conditions, convergent evolution would be expected. Due to the very different climatic conditions between Year 1 and Years 2-4 after restoration, average temperature conditions within the Project Area and in the Reference Areas fluctuated sharply, driven by strong variation in the amount of inflow of cold freshwater from the upper watersheds and, in some cases, groundwater. Temperatures might be expected to range a little lower in the Project Area than reference marshes due to the strong influence of Lagunitas Creek, the largest creek in the Tomales Bay watershed, and numerous other creeks and groundwater seeps. However, despite this, average salinities after restoration during Years 1 through 4 did not differ significantly between the Project Area (15.2 ± 0.2 (S.E.) degrees Centigrade) and Reference Areas (15.3 ± 0.3 (S.E.) degrees Centigrade; GLM, df=1, F<0.0001, P=0.991), although temperatures did differ significantly between years (GLM, df=3, F=5,86, P=0.001).

While these results would suggest that the Project Area is converging with conditions in the Reference Areas, the Project Area will probably never totally converge with that of the Reference Areas due to its geographic position within the freshwater-saltwater interface zone, although both spatial and temporal pattern of salinities and temperatures will continue to change as conditions evolve after restoration.

pH

Another variable that shows the influence of freshwater is pH. While pH prior to restoration might have been expected to be lower in the freshwater-dominated Project Area compared to the more marine-influenced Reference Areas –- pH of ocean waters is typically somewhat alkaline –- Pre-Restoration pH did not vary significantly between the Project Area and the other Study Areas prior to restoration (range=7.60 to 7.63 in Upstream Areas; Kruskal-Wallis, df=2, H=5.09, P=0.08; Parsons 2009). Most creeks feeding into the Project Area actually had fairly high pHs (range = 7.7 – 8.1) regardless of differences in geologic substrate between the granitic Inverness Ridge and the Point Reyes Mesa coastal marine terrace and surrounding Franciscan Formation hills, which are separated by the San Andreas Fault that created this tectonic estuary (ibid). Muted tidal influence in the West Pasture and Tomasini Creek and high primary productivity during some sampling events also boosted pH (ibid). However, lower pH waters (~5.9 – 6.6) occurred only in areas where more extensive influence from groundwater occurs or, less frequently, where there was organic matter decomposition actively occurring (ibid).

While introduction of full tidal flows to the Project Area might have been expected to boost pH, the mean pH in the Project Area has actually declined consistently since dairy operation, dropping approximately 5% from 7.58 ± 0.02 during Pre-Restoration to 7.29 ± 0.06 during Passive Restoration and 7.21 ± 0.02 during Full Restoration (GLM, df=2, F=70.3, P<0.0001; Figure 6). Median pH values also appeared to drop from 7.60 during Pre-Restoration to 7.30 during Passive Restoration and 7.23 during Full Restoration (Mood Median test, df=2, Chi-Square=114.6, P<0.0001; Figure 6). Median pH during the first three years after restoration was 7.25 during Year 1, 7.14 during Year 2, 7.26 during Year 3, and 7.22 during Year 4. As early sampling efforts only included pH of surface waters, medians from later sampling periods – primarily post-restoration – were re-run using just surface water values to ensure that more recent values were not being potentially affected by lower pH values in bottom waters. However, the values for just surface values were identical to those of the averaged surface and bottom waters.

The increase in tidal exchange and decrease in water residence time after levees were removed may have led to decreases in pH associated with phytoplankton blooms. However, breakdown of organic matter from die-off of pasture vegetation can also increase release of humic acids into overlying Project Area waters, resulting in a decrease in pH. In addition, flushing of sulfuric and iron-associated acids from oxidation of reduced sulfur and iron complexes in soils into overlying waters can also decrease pH: sulfuric and iron-associated acids are generated when pyrites or other reduced or anoxic forms of sulfate and iron in the soil are oxidized and broken down or converted during drawdown or low-water periods, with soluble acids from oxidation then released into overlying waters when tidal exchange is reintroduced. The Project Area was deliberately dried out before and during construction to improve constructability conditions, resulting in even drier conditions than when the Project Area was ranched. An iron-colored crust coats some of bottoms of the newly created tidal creeks in the East Pasture, suggesting that iron is being mobilized from soils, which may affect pH in these areas.

Four years following restoration, pHs in the Project Area and Reference Areas still appear to differ from each other (GLM, df=1, F=10.1, P=0.002), with pH averaging 7.21 ± 0.02 (S.E.) in the Project Area and 7.32 ± 0.03 (S.E.) in the Reference Areas. Some of this difference may relate to the greater influence of lower pH groundwater inflow on the Project Area than Reference Areas. However, despite these differences, both Study Areas experienced a weakly significant drop in pH over the post-restoration sampling period (GLM, df=3, F=2.39, P=0.067), with Year 1 (7.33 ± 0.04 (S.E.) appearing different from Years 2 and 3 (7.21 ±0.04; all P<0.08; Figure 6).

This trend is evident in a similar seemingly slight, but significant, decrease in pH in Reference Areas over the entire sampling period (Figure 6). In Reference Areas, pH dropped 5% from 7.67 ± 0.03 (S.E.) during the Pre-Restoration sampling period to 7.53 ± 0.05 (S.E.) during the Passive Restoration period and 7.32 ± 0.03 (S.E.) during the Full Restoration period (GLM, df=2, F=35.0, P<0.0001), with pH during all three sampling periods being significantly different from each other (P<0.05). Median pH showed a slightly different pattern, being roughly equivalent in Pre- and Passive Restoration sampling periods (7.62) and then dropping during the Full Restoration period (7.33; Mood Median Test, df=2, Chi-Square=42.1, P<0.0001). The pH following restoration in Reference Areas was 7.47 ± 0.06 (S.E.; 7.44) during Year 1; 7.28 ± 0.06 (S.E.; 7.28) during Year 2; 7.30 ± 0.08 (S.E.; 7.32) during Year 3, and 7.30 ± 0.06 (S.E.; 7.31) during Year 4.

In looking at the data more closely, it appears that, starting in WY 2007, prior to restoration, the median pH for Reference Areas started declining until WY 2010, when values appear to have roughly stabilized around 7.30. The median pH appears to have dropped most in the Undiked Marsh, which is furthest from the mouth of Tomales Bay, and Limantour Marsh, which is in another watershed, than in Walker Creek Marsh, which is located close to the mouth of Tomales Bay. During Pre-Restoration and Year 4 periods, the median pH averaged 7.48 and 7.31, respectively, in the Undiked Marsh; 7.80 and 7.22, respectively, in Limantour Marsh, and 7.70 and 7.53, respectively, for Walker Creek Marsh. Consistent with the overall trend, pHs in Limantour Marsh and the Undiked Marsh appeared relatively stable until WY 2007, when values began to seemingly show a decline. In contract, Walker Creek Marsh has maintained relatively consistent pH levels around 7.65-7.70 except for Years 2 and 4 post-restoration: Results from Years 2 and 4 may represent more year-to-year variation than a potential trend indicator.

The seeming downward trend in median pHs in the Undiked Marsh and Limantour Marsh since WY 2007 could potentially result from the fact that, in these systems, upstream areas have been restored, and restoration is affecting the pH of downstream marshes, as well as that of the Project Areas. However, pHs in more distant areas of Tomales Bay were also lower during this period, as well. University of California, Davis, (UC Davis) researcher Ann Russell and her colleagues temporarily reoccupied the Tomales Bay sampling stations established by the Land Margin Ecological Research (LMER) program in the 1980s as part of a current research effort to understand the impacts of ocean acidification and climate change on estuarine invertebrates. During LMER, sampling was conducted at 10 stations from the outer Tomales Bay near the mouth to the southernmost one some distance north of the Undiked Marsh between 1987 and 1995. Russell reinitiated sampling in fall 2008 just when the restoration project was almost complete. During sampling efforts from 2008 to 2010, Russell has found no difference in most of the field parameters between the LMER and recently collected data, however, pH did appear to have declined in both the outer and inner Bay by as much as 0.25 pH units (A. Russell, UC Davis, *pers. comm*.).

While apparent decreases in pH in Tomales Bay and its marshes might lead to questions about the effect of ocean acidification on pH of tidal waters flowing into estuaries, there are several factors that throw this into question. While Russell and colleagues did observe larger decreases in pH in the Outer Bay relative to the Inner Bay (Russell et al. 2010), in our results, pH decline appears to have been greatest furthest from the mouth of the estuary, which suggests that, for our study, changes are not directly related to inflow of lower pH waters from the ocean. Russell believes that the change observed in pH for Tomales Bay was too large to be attributable to dissolution of CO^2 from the atmosphere into estuarine waters (A. Russell, UC Davis, *pers. comm*.). However, not all carbon inputs into the estuary come from the atmosphere (ibid). In addition to changes in pH, concentrations of dissolved organic carbon (DOC) and, in the Outer Bay, dissolved inorganic carbon (DIC) also appeared higher relative to the LMER program sampling period (Russell et al. 2010).

Some of these differences may relate to the fact that the sampling period during the study implemented by Russell and her colleagues was during a wetter period than the LMER sampling period (J. Largier, UC Davis, *pers. comm*.). This would also affect transport of carbon from the upper watershed into the Bay. At least in terms of the Park Service's dataset, cumulative rainfall volume did appear slightly higher during the post-restoration sampling period (mean for Oct 2008-Sept 2012 =3.51 in > normal) than the pre-restoration one (mean for Oct 2004-Sept 2008=0.70 in>normal; Figure 1). This would increase freshwater inflow from both surface water and groundwater sources, which tends to be lower in pH than tidal waters: this is evident in the generally lower range of values for the Upstream Areas during the post-restoration sampling period (Figure 6). In particular, the groundwater outflow in this area tends to have a slightly lower pH: these factors could affect pH within the restored wetlands, above and beyond any restoration effect. In addition, while these pH changes may be unrelated to ocean acidification, it does not rule out that we may begin to see changes related to climate change in future years, although pH in estuaries is normally more highly variable than that of oceans even without the influence of climate change.

Dissolved Oxygen

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While diking did not appear to negatively impact salinities, temperature, or pH of waters within the unrestored Project Area, diking and other agricultural land management practices did appear to affect oxygen concentrations within drainage ditch and creek waters, often causing hypoxic or even anoxic conditions (Parsons 2009). Most of the extremely low oxygen concentrations occurred in the East Pasture drainage ditches, where frequent ditching increased oxygen demand by filling ditch waters with loose vegetation material that was consumed by oxygen-dependent bacteria (ibid). This management practice, coupled with the relatively infrequent exchange or subsidy of ditch waters except during the winter or when irrigation was performed, typically kept oxygen levels below 5 mg/L and often below 2 mg/L (ibid).

Prior to restoration, oxygen levels in the East Pasture averaged 4.98 ± 0.24 (S.E.) mg/L, with median levels actually being slightly lower (4.56 mg/L; Parsons 2009). These same factors – copious amount of organic matter and infrequent exchange between the impounded marsh and Lagunitas Creek -- also contributed to consistently low levels of oxygen in Olema Marsh, although levels were not as low as the East Pasture (mean = 5.83 mg/L; ibid). Median oxygen concentrations in other Project Area sampling locations – excluding upstream sampling sites -- ranged from 8.64 mg/L in Lagunitas Creek to 7.91 mg/L for Tomasini Creek, with the less heavily managed West Pasture having slightly higher levels (8.50 mg/L; ibid).

Following restoration, mean oxygen levels in the Project Area increased 14% from 7.30 ± 0.13 (S.E.) mg/L during Pre-Restoration to 8.55 ± 0.35 (S.E.) mg/L during Passive Restoration and 8.30 ± 0.14 (S.E.) mg/L during Full Restoration (GLM, df=2, F=24.3, P<0.0001; log transformed for analysis), with Full and Passive Restoration periods differing significantly from Pre-Restoration (all P<0.0001; Figure 7). Median oxygen levels in the Project Area climbed from 7.58 mg/L during Pre-Restoration to 8.40 mg/L during Passive Restoration and 8.31 mg/L during Full Restoration (Mood Median, df=2, Chi-Square=20.3, P<0.0001; Figure 7). After restoration, oxygen showed some interannual variability, averaging 8.73 ± 0.39 (S.E.) mg/L in Year 1; 7.79 ± 0.24 (S.E.) mg/L in Year 2; 8.06 ± 0.24 (S.E.) mg/L in Year 3; and 8.70 ± 0.24 (S.E.) mg/L in Year 4 after Full Restoration. Lower D.O. levels occurred in Year 2 than Years 1, 2, and 4: both Years 2 and 3 were quite wet, although the Year 2 sampling approach may have captured more storm events. Cold temperatures and strong flow conditions could suppress biological activity in waters relative to warmer, more quiescent periods. However, based on values from both Project and Reference Areas, oxygen levels did not strongly differ between years following restoration (GLM, df=3, F=1.69, P=0.17, log transformed for analysis). Mean oxygen levels in Reference Areas remained similar during the post-restoration sampling period (8.86 ± 0.36 (S.E.) mg/L) and pre-restoration sampling period (8.66 ± 0.15 (S.E.) mg/L； GLM, df=2, F=1.2, P=0.30).

Oxygen concentrations in the East Pasture jumped 61% from 4.98 ± 0.24 (S.E.) mg/L pre-restoration to 8.04 ± 0.86 (S.E.) mg/L during the passive phase and then climbed another 4% to 8.39 ± 0.21 (S.E.) after restoration (GLM, df=2, F=59.9, P<0.0001; log transformed for analysis; Figure 7). Similarly, median values also increased from 4.56 mg/L pre-restoration to 8.30 mg/L after restoration (Mood Median, df=2, Chi-Square=88.1, P<0.0001; Figure 7). Oxygen concentrations have varied considerably interannually, averaging 9.89 ± 0.49 (S.E.) mg/L during Year 1; 8.27 ± 0.37 (S.E.) mg/L during Year 2; 7.74 ± 0.38 (S.E.) mg/L during Year 3, and 7.99 ± 0.41 (S.E.) mg/L during Year 4.

In the Project Area, oxygen concentrations prior to restoration fell below the Basin Plan standard of 5 mg/L during 25% of the sampling periods, with most of these exceedances occurring in the East Pasture (Parsons 2009). In contrast, only approximately 8% of the oxygen concentrations recorded in reference marshes fell below 5 mg/L, a difference of 68% (ibid). After Full Restoration, the number of Basin Plan standard exceedances in the Project Area dropped 43% from 25% to 14.2% in Year 1 and 4% in Year 2, rising slightly to 13.5% again in Year 3 and then dropping again to 7% in Year 4. Year 4 exceedances in the restored wetland were seemingly slightly lower than Reference Areas (10%). There were no incidences of hypoxia (< 2 mg/L) or anoxia (<0.5 mg/L) in the Project Area in Year 4, compared to 3.2% and 0.1%, respectively, in Year 3 and 12.2% and 5.4%, respectively, prior to restoration. These were the lowest levels of hypoxia and anoxia ever recorded in the Project Area.

With restoration, oxygen concentrations might have been expected to decrease – or only increase somewhat overall – due to the abundant organic matter that die-off of pasture vegetation that has been released into Project Area waters during the first year and even second year of restoration. With high levels of organic matter, bacteria become extremely active and rapidly deplete oxygen levels in overlying waters, particularly during the night, when oxygen stores are not replenished through primary production. While pasture vegetation went through multiple stages of die-off in the first year and even subsequent years, the effect of this die-off has not been evident in Project Area oxygen concentrations, and, in fact, oxygen levels between these two Study Areas after restoration were equivalent from a statistical perspective: 8.30 ± 0.14 (S.E.) mg/L in the Project Area and 8.86 ± 0.36 (S.E.) mg/L in Reference Areas (GLM, df=1, F=1.09, P=0.30, log-transformed for analysis).

Turbidity

Prior to restoration, turbidity levels appeared to differ at least slightly between the Project Area (median=10.7 NTU) and Reference Areas (median=12.2 NTU), with Upstream Areas having the lowest levels (median=5.7 NTU; Kruskal-Wallis, df=2, H=43.0, p<0.0001; Parsons 2009). This same pattern was apparent with mean turbidity levels, with values estimated at 22.7 ± 2.3 (S.E.) NTU for the Project Area, 19.9 ± 1.5 (S.E.) NTU for Reference Areas and 13.4 ± 1.8 (S.E.) NTU for Upstream Areas (ibid). Based on this, it would appear that turbidity levels were similar between the Project Area and Reference Areas, but much lower in the fluvially dominated Upstream Area portions of the system.

Before levee removal, differences also existed within the Project Area itself. Turbidity levels were higher in the heavily managed East Pasture (median=13.5 NTU) than in the other Project Area sub-groups, which ranged from a median of 8.0 NTU in the West Pasture to 11.3 NTU in Olema Marsh (Kruskal-Wallis, df=4, H=24.0, p<0.001; ibid). The disparity between sub-sampling areas was even more apparent with means, with turbidity averaging 36.6 ± 97.0 (SD) NTU in the East Pasture and 13.3 ± 18.25 (SD) NTU in the more lightly managed West Pasture (ibid). These numbers do not necessarily correspond with those discussed earlier in this section, because they exclude upstream sampling sites.

The highest measured turbidity Pre-Restoration occurred at the downstream sampling station near the Giacomini Ranch North Levee in June 2003 with a value of 266 NTU (Parsons 2009). In general, before the levees were removed, turbidity fell below 50 NTU in Lagunitas and Fish Hatchery Creeks and 40 NTU in Tomasini Creek (ibid). Turbidity did show a somewhat unexpected temporal trend, with the highest values in spring, summer, or early fall: turbidity is typically expected to be highest during the winter when sediment is being actively moved by creeks (ibid). The production of suspended particles during these periods may have been due to events such as upstream dam releases, biological activity, cattle activity, tidal action, and other activities within streams, ditches, and other water bodies.

Turbidity would be expected to increase, at least temporarily, following restoration due to the resuspension of sediment disturbed by excavation and other construction activities, die-off of pasture vegetation, and evolution of the marsh surface in response to tides and stormwater flows. In addition, release of decomposing organic matter into overlying waters would decrease clarity. As noted above under Hydrology, sediment efflux does appear to be occurring, based on the formation of ebb shoals at the confluence of newly constructed primary tidal channels in Lagunitas Creek (KHE 2009). Interestingly, however, turbidity levels in the Project Area showed no significant differences between pre- and post-restoration during Year 1 (ANOVA, df=2, F=1.2, P=0.30; Figure 8). Median turbidity levels were estimated at 10.7 NTU in the first year of Full Restoration, compared to 10.7 NTU during Pre-Restoration and 10.5 NTU during Passive Restoration.

However, in Year 2 after restoration, differences did exist between pre and post-restoration, with median turbidity levels almost doubling from 10.7 NTU to 22.2 NTU during Year 2 (Mood Median Test, df=3, Chi-Square=35.70, P=<0.0001; Figure 8). Means also seemingly jumped during Year 2, averaging 60.8 ± 11.2 (S.E.) NTU during Year 2 relative to 22.7 ± 2.3 (S.E.) NTU during Pre-Restoration; 40.0 ± 13.7 (S.E.) NTU during Passive Restoration; and 15.7 ± 1.6 (S.E.) NTU during Year 1. While median turbidity levels in the Project Area did not differ significantly from Reference Areas in Year 1 (median=10.1 NTU; Mood Median Test, df=2, Chi-Square=0.20, P=0.906), they did differ significantly in Year 2 (Reference Area median=13.3 NTU; df=2, Chi-Square=11.32, P=0.003). In Year 3, turbidity levels dropped somewhat relative to Year 2, averaging 21.3 ± 3.6 (S.E.) NTU, which was seemingly equivalent to average turbidity levels during Pre-Restoration, but higher than Year 1.

In Year 4, turbidity levels climbed again (32.6 ± 6.6 (S.E.) NTU), although levels still appeared much lower than Year 2 (Figure 8). Overall, because of increases in Year 2 and Year 4, turbidity levels appeared to increase by 49% as a result of restoration (GLM, df=2, F=9.82, P<0.0001), with significant differences occurring between Pre- (22.7 ± 2.3 (S.E.) NTU) and Full-Restoration (33.8 ± 3.7 (S.E.) NTU; P=0.02) sampling periods.

The very disparate trends in turbidity levels between Years 1 and 3 and Years 2 and 4 following restoration may be largely due to very different climatic conditions between these years. In WY 2008, conditions were relatively dry due to low rainfall and low-energy storm events, with no overbank flooding occurring that year. With higher rainfall, scour of the new channels and flooding of the still evolving marshplain would at least temporarily increase resuspension of sediment into overlying waters. Because rainfall was so low in Year 1, most of the "re-working" in the Project Area marsh came solely from tides, although they, in conjunction with vegetation die-off, would have been expected to increase turbidity within Project Area waters. As noted earlier, shoaling at creek mouths show that re-working of the landscape was taking place, even without the influence of storm events.

In Year 2 (WY 2010), rainfall totals jumped, and 50% of the sampling events occurred during moderate to large storm events, although there was still no overbank flooding, at least from Lagunitas Creek. The fact that turbidity levels were significantly higher in the Project Area than in the Reference Areas suggests that turbidity levels in the restoring wetlands exceeded those that would be expected in mature marshes simply based on normal sediment resuspension pulses during storm events. Therefore, Year 2 may have better represented the short-term increase in turbidity levels immediately after restoration that was predicted in the environmental compliance analysis documents.

Interestingly, Year 3 (WY 2011) was also wet, but turbidity levels decreased during that year. This may represent an artifact of sampling effort – that is, more samples were taken during storm events in Year 2 (50% of sampling events) than Year 3 (33% of sampling events) – but storm sampling was conducted in Year 3, as well. Also, the rainy season was prolonged in Year 3, allowing more potential to capture turbidity-generating events. Year 4 (WY 12) was dry during the winter months, but rainier than normal during the spring period. However, the fact that only some of the fall sampling events occurred during any type of rainfall event, however small, suggests that other factors might have been increasing turbidity during the past years, perhaps both physical (reworking of soils by tides, creek flow) and biological.

However, to keep climatic contribution in perspective, during this same period, turbidity remained roughly equivalent in Reference Areas, with Pre-Restoration averaging 19.9 ± 1.5 NTU and Full Restoration averaging 16.4 ± 0.8 NTU (GLM, df=2, F=1.3, P=0.27, log-transformed for analysis). This would suggest that the Project Area is responding to restoration effects. Therefore, it is not surprising that a strong interaction factor appeared to exist between Study Area and post-restoration sampling year (GLM, df=3, F=7.62, P<0.0001, log transformed for analysis), which suggests that the Study Areas responded differently during the different treatment years (all P<0.02). Following restoration, turbidity averaged 33.8 ± 3.7 (S.E.) NTU in the Project Area, almost twice that of Reference Areas (16.4 ± 0.8 (S.E.) NTU). Median turbidity levels, however, did not significantly differ between the Project Area (14.6 NTU) and Reference Areas (12.8 NTU) after restoration (Mood Median, df-1, Chi-Square=2.12, P=0.15), which suggests that either high turbidity sites or turbidity pulses are driving mean turbidity levels up in the Project Area.

Nitrates Predominant Nutrient Source Particularly in Ranch Prior to Restoration, but Levels Already Decreasing After Restoration

Nitrates

The relatively well oxygenated conditions present in most of the Study Areas -- except the East Pasture prior to restoration – may contribute to the dominance of nitrates as the primary source of nutrients in the Study Areas (Parsons 2009). In contrast to ammonia and phosphates, nitrates have only very infrequently fallen below detection limits, even at relatively high limits used by commercial laboratories. Results from the LMER/BRIE study conducted a decade earlier – which were, at least for Bay samples, generally much lower in magnitude than our pre-restoration results – also showed nitrates as being the predominant source of nutrients (ibid). In our study, average nitrate concentrations did differ prior to restoration between Major Study Area groups, although median concentrations within the Project Area (0.83 mg/L) were actually not considered significantly different from those in the Reference Areas (0.70 mg/L; ibid).

Prior to restoration, the Project Area mean was substantially influenced by consistently high values in the more heavily managed East Pasture, which supported two active dairy herds, as well as being more actively managed in terms of irrigation, manure spreading, haying, land leveling, and other actions. Within the Project Area (excluding upstream sampling sites), estimated nitrate concentrations averaged 7.25 ± 1.83 (S.E.) mg/L (NO3-) for the East Pasture and then dropped to below 1.10 mg/L for the other sub-groups (Parsons 2009). While nitrate concentrations were lower in less heavily managed portions of the Project Area, these areas were still subject to nitrate inputs from passive agricultural management of the West Pasture (e.g., grazing of dry or less active dairy herds); dairy use of Lagunitas Creek both inside and directly upstream of the Project Area; loading from upstream portions of Lagunitas, Tomasini, and Fish Hatchery Creeks; non-point source run-off and stormwater flow from the town of Point Reyes Station; and potential influence of leaking septic systems into groundwater that flows along the perimeter of the Giacomini Ranch and Olema Marsh (ibid).

The similarity in median nitrate concentrations between the Project Area and Reference Areas and even among the different Reference Area units – all of which occur in different watersheds or subwatersheds -- suggests that nitrogen and other nutrients are strongly controlled by internal, as well as external, factors (Parsons 2009). Indeed, these factors at times appear to override the differences in concentrations and loading that would be expected from the three Reference Area units given the very substantial difference in the degree and type of agricultural and residential development in the respective subwatersheds. While concentrations of nitrates were highest in winter and fall sampling events in the Project Area, there were occasionally spikes or pulses in spring or summer that were unrelated to increases in streamflow with storm events or run-off (ibid). Some of the pulses in nitrates during non-flood periods may result from inorganic nutrients being regenerated “internally” from breakdown of organic matter within marshes (Chambers et al. 1994b; ibid).

Immediately following restoration, a sharp pulse in nitrates did occur. In November 2008, only a few weeks after the levee was breached, estimated nitrate concentrations averaged 3.44 ± 1.59 (S.E.) mg/L, with median concentrations of 1.60 mg/L, however, by January 2009, estimated concentrations had dropped to an average of 0.18 ± 0.08 (S.E.) mg/L and median of 0.13 mg/L, which were seemingly higher, but not significantly so from August 2009 (est. average=0.06 ± 0.04 (S.E.) mg/L) and May 2009 (est. average=0.02 ± 0.01 (S.E.) mg/L) events. Estimated nitrate concentrations showed a statistically significant relationship with sampling date in WY 2009, with January, May, and August 2009 sampling results differing significantly from November 2008, and the two February 2009 storm sampling events (MLE, df=5, Chi-Square=20.0, $p<0.0001$). So, following the early transitional period after levee breaching, the only recorded surge in nitrates occurred during the two February 2009 storm sampling events, where estimated nitrates climbed to average levels between 1.63 and 1.93 mg/L and median levels between 1.6 and 2.0 mg/L during both events due to strong pulses at certain Project Area sampling sites. It should be noted that average levels recorded during non-storm events between January 2009 and August 2009 in the Project Area were roughly half that of Reference Areas.

Despite these episodic pulses, estimated mean nitrate concentrations did appear to actually decrease from 3.22 ± 0.72 (S.E.) mg/L Pre-Restoration to 0.94 ± 0.35 (S.E.) mg/L during Year 1 of Full Restoration, which also represented a drop from levels during Passive Restoration (4.52 ± 2.35 (S.E.) mg/L; Figure 9). In Year 2, estimated mean nitrate concentrations dropped even further to 0.63 ± 0.12 (S.E.) mg/L, but they climbed again in Year 3 to 1.02 ± 0.12 (S.E.) mg/l and again in Year 4, doubling relative to Year 3 to 2.00 ± 1.00 (S.E.) mg/l ; Figure 9). A slightly different pattern was observed with median nitrate levels. During Year 1 post-restoration, median nitrate concentrations plummeted to 0.04 mg/L in Year 1, but then rose again in subsequent years to 0.38 mg/L in Year 2, 0.28 mg/L in Year 3, and 0.25 mg/L in Year 4 (Figure 9)

Despite increases in nitrate concentrations during recent years, nitrate concentrations during Full Restoration (1.16 ± 0.31 (S.E.) mg/L) were still 64% lower than those during recorded prior to restoration (3.22 ± 0.72 (S.E.) mg/L; <0.0001), but statistically equivalent to levels recorded during Passive Restoration (4.52 ± 2.35 (S.E.) mg/L; P=0.14) levels (GLM, df=2, F=11.86, P<00001; data log-transformed for analysis; Figure 9). A slightly different trend appeared to occur with estimated medians, which perhaps better reflect "average" conditions as they are not affected by localized hot spots or one-time spikes in nutrients. Estimated median nitrate values dropped from 0.83 mg/L Pre-Restoration to 0.37 mg/L during Passive Restoration and 0.26 during Full Restoration (Mood Median, df=2, Chi-Square=45.6, P=<0.0001; Figure 9). The difference between patterns in mean and median levels suggest that certain sites or sampling events have elevated mean nitrate levels: this could possibly be the influence of a non-point source discharge from Point Reyes Station into one of the restored wetland features, which is sporadically elevating nitrate concentrations during certain sampling periods. In addition, "increases" in more recent sampling years may be at least partially attributable to an increase in sampling frequency of this restored wetland feature. This is described in more detail below.

Interestingly, Year 1 -- which had very low median nitrate levels following restoration -- was one of the drier years after the levees were breached while Year 2 -- which had the lowest mean nitrate concentrations, but higher median concentrations -- was one of the wettest: Years 3 and 4 had either slightly above or below average rainfall, respectively, and the patterns of rainfall distribution were very different (Figure 1). In addition to climatic patterns, sampling patterns may have also influenced results, as, during Years 2 and 3, 50% of the sampling periods in Year 2 and 33% in Year 3 occurred during moderate to large storm events, whereas only a few smaller storm events were captured during fall sampling efforts in Year 4. A large storm (7.0 inches) did directly precede the winter or January sampling event.

The influence of rainfall patterns is evident in results for Reference Areas, as well (Figure 9). Both estimated mean and median nitrate concentrations appeared higher in Year 2 (0.76 ± 0.18 (S.E.) mg/L and 0.34 mg/L) than in Year 1 (0.35 mg/L ± 0.15 (S.E.) and 0.07 mg/L) and Year 3 (0.34 ± 0.04 (S.E.) mg/L and 0.29 mg/L; Wilcoxon, df=4, Chi-Square=67.7, P<0.0001; Figure 9). However, Year 4, which had similar rainfall totals to Year 1, had nitrate levels more similar to Year 2, with estimated means being 0.64 ± 0.12 (S.E.) mg/L and the median being 0.37 mg/L. This suggests, as discussed earlier, that other factors may influence nitrate levels other than watershed loading. Interestingly, estimated median nitrate levels appeared to drop after the Pre-Restoration period from 0.70 mg/L to 0.13 mg/L during Passive Restoration (~2007 – 2008) and then climb slightly again to 0.27 mg/L during Full Restoration (Mood Median, df=2, Chi-Square=50.9, P<0.0001). The same pattern was also evident in estimated mean nitrate levels, which also appeared to decrease almost 40% from 0.88 ± 0.05 (S.E.) mg/L during Pre-Restoration to 0.36 ± 0.08 (S.E.) mg/L during Passive Restoration and then increase again during Full Restoration to 0.53 ± 0.07 (S.E.) mg/L (Figure 9).

While one of the Reference Area marshes is located directly adjacent to the Project Area, the other two locations are at the southern end of Tomales Bay and in another watershed completely, so increases in nitrate levels following restoration cannot be ascribed entirely to the restoration project, particularly as waters only infrequently discharged from the more heavily managed – and polluted – parts of the Project Area downstream. In fact, both the proximal and distant Reference Areas in Tomales Bay showed similar temporal patterns in nitrate levels, as well as equivalent Pre-Restoration concentrations, with estimated means ranging from 0.84 to 0.89 mg/L and estimated medians, from 0.68 to 0.77 mg/L. These concentrations fell to between 0.07 and 0.18 mg/L for all reference marshes during Passive Restoration and then climbed again to between 0.24 and 0.28 mg/L following restoration. Ironically, more storm events were sampled after 2006 than prior to that time, so a higher frequency of storm samples prior to 2006 cannot explain this downward trend in nitrate levels within Reference Areas.

In most of the Project and Reference Areas, nitrates never exceeded USEPA water quality objectives of 10 mg/L as nitrate-N (or 44 mg/L as NO3) for human consumption, even prior to restoration (Parsons 2009). However, in the East Pasture, approximately 7% of the nitrate samples collected exceeded 44 mg/L prior to restoration, with most of the exceedances coming from a ditch at the base of the Dairy Mesa that receives non-point source run-off from Point Reyes Station, as well as potentially septic-influenced groundwater (ibid; Figure 9). This same Upstream Area boundary sampling site continues to show elevated nitrates even after restoration and exceeded 10 mg/L during every sampling event in Years 2, 3, and 4 and 75% of the events in Year 1 (Figure 9). Nitrate concentrations at this site ranged from 18.1 mg/L (October 2011) to 47.2 (January 2012). Indeed, following restoration, nitrate pulses from this discharge source far surpassed any spikes in nitrate concentrations in Upstream Area creeks that might have been expected during large storm events (Figure 9). The highest nitrate levels in the Project Area in Years 3 and 4 occurred in the Tomasini Triangle Pond, which is a created freshwater marsh that receives the non-point source run-off and septic influenced groundwater from the sampling site described above (Figure 9). Nitrate levels in this pond during Year 3 ranged from 7.02 mg/L in July 2011 to 23.87 in mg/L in January 2011, and, in Year 4, they ranged from 0.03 mg/L in July 2012 to 46.3 mg/L in January 2012.

Perhaps because of these issues, nitrate concentrations between the Project Area and Reference Areas still differed significantly by Year 4 of Full Restoration (GLM, df=1, F=6.46, P=0.01; log-transformed for analysis), and there were also significant differences between Study Areas and sampling years (GLM, df=3, F=2.63, P=0.05; log-transformed for analysis). Nitrate concentrations averaged 1.16 ± 0.31 (S.E.) mg/L in the Project Area and 0.53 ± 0.07 (S.E.) mg/L in Reference Areas during the four years after restoration was implemented. Median concentrations between Study Areas were much closer, with no significant differences existing between medians in the Project Area (0,26 mg/L) and those in Reference Areas (0.27 mg/L; Mood Median test, df=1, Chi-Square=0.05; P=0.83). Based on these results, earlier analyses were re-run without the created freshwater marsh values: mean nitrate concentrations now appeared more similar from a statistical standpoint between the Project Area (0.70 ± 0.10 (S.E.) mg/L) and Reference Areas (0.53 ± 0.07 (S.E.) mg/L; GLM, df=1, F=2.06, P=0.15; log-transformed for analysis).

Interestingly, nitrites were generally not detected (<0.05 mg/L), in the Project Area prior to restoration, but they were occasionally found in Reference Areas, with Walker Creek and Limantour Marsh both having six (6) detections, although only three (3) samples exceeded RWQCB recommended thresholds of 0.5 mg/L (ibid). Because nitrites were only rarely recorded prior to restoration, they were not specifically sampled during the Passive Restoration and Full Restoration sampling periods.

Ammonia

Prior to restoration, most of the ammonia pulses in the Project Area occurred in waters with lower oxygen (or pH) levels and appeared more related to cattle grazing and other management practices such as ditch maintenance than with timing of storm inflows or run-off (Parsons 2009). Cattle grazing provided a source of ammonia that would be maintained in low oxygen waters, while ditch maintenance promoted hypoxic conditions by increasing organic matter available for mineral decomposition and creating a surge in biological oxygen demand. These conditions favored retention of nitrogen as ammonia rather than as nitrates.

Within the Project Area (excluding upstream sites), estimated ammonia concentrations Pre-Restoration in the East Pasture averaged 2.61 ± 1.51 (S.E.) mg/L, which differed significantly from values estimated for the West Pasture (0.45 ± 0.24 (S.E.) mg/L) and Tomasini Creek (0.20 ± 0.01 (S.E.) mg/L; Wilcoxon Score, p<0.001; ibid). However, because of the high number of non-detects during Pre-Restoration due to use of a commercial laboratory, a more valid parameter might be the distribution of “detections” among sampling sites. Of the 64 detections of ammonia during the Pre-Restoration period, more than 47 % of them occurred in the East Pasture, a substantial – and statistically significant – difference from the other Project and Reference Area subsampling areas that accounted for no more than 11 % of the detections (Contingency Table, Chi Square, df=4, Chi-Square=13.4, p=0.009; ibid).

Overall, there was apparently no statistically significant differences in the number of detections between Study Areas Pre-Restoration (Contingency Table, Chi Square, n=320, df=2, Chi-Square=2.70, p=0.26; Parsons 2009). However, before levees were breached, estimated concentrations appeared to be substantially higher in the Project Area (mean = 1.26 ± 0.58 (S.E.) mg/L) than in the Reference Areas (mean = 0.23 ± 0.01 (S.E.) mg/L) or Upstream Areas (mean = 0.22 ± 0.01 (S.E.) mg/L; Wilcoxon, p<0.001; Wilcoxon Score, df=2, Chi-Square=22.46, p<0.001, ibid). Ammonia pulses in Reference Areas prior to restoration most likely resulted from decreases in oxygen levels in tidal creek waters due to high primary productivity and subsequent respiration or an increase in water residency time than from point-source loading. Conversely, sporadic pulses in creeks such as Lagunitas and Walker Creek probably related more to point-source loading or an immediately proximal source of ammonia than to the presence of a low oxygen environment.

Following restoration, the number of ammonia detections decreased in the Project Area (Contingency, df=2, Chi-Square=12.1, P=0.002), with the number of detections dropping from 23% during Pre-Restoration to 4.6% during Passive Restoration and 11.9% during Full Restoration (Figure 10). In Year 1, detections dropped 43% from 22.8% of the samples Pre-Restoration to 14.0% of the samples (Figure 10). The number of total ammonia detections decreased even more dramatically in Year 2 of Full Restoration, dropping 48% to 6.8% of the samples exceeding detection limits (Figure 10). In Years 3 and 4, detections climbed again to 11.1% of the samples in Year 3 and 15.9% of the samples in Year 4, but were still seemingly lower than Pre-Restoration (Figure 10). Interestingly, as noted above, the number of detections was lowest during Passive Restoration (4.6%; Figure 10).

Estimated mean total ammonia concentrations within the Project Area did appear to drop 73%-88% after restoration from 1.26 ± 0.58 (S.E.) mg/L Pre-Restoration to 0.34 ± 0.10 (S.E.) mg/L during Year 1. High variability may have reduced power of analysis, as seeming differences between restoration phases were not statistically significant (Wilcoxon, df=4, Chi-Square=7.04, P=0.13). Estimated East Pasture mean ammonia concentrations appeared to drop even more dramatically from 2.61 ± 1.51 (S.E.) mg/L to 0.44 ± 1.51 (S.E.) mg/L in Year 1 and 0.24 ± 0.15 (S.E.) mg/L in Year 2, a decrease of 83% and 91%, respectively, from Pre-Restoration levels (Wilcoxon, df=4, Chi-Square=14.7, P=0.005).

Estimates of total ammonia concentrations must be interpreted with caution due to the fact that the number of non-detects makes estimating concentrations difficult, even with use of methods for non-detect data. Dissolved ammonia samples were only collected during the Passive and Full Restoration phases, but they have much lower detection limits than total ammonia, which, thereby, reduces the number of non-detect samples. There are some similarities with estimated total ammonia, although dissolved ammonia concentrations, overall, were much lower. While differences in dissolved ammonia levels appeared to occur between treatment years during Passive and Full Restoration, they were not statistically significant, perhaps due to high variability in the data (GLM, df=4, F=1.15, P=0.33; log-transformed for analysis). Some of the lowest dissolved ammonia levels occurred during Passive Restoration (0.15 ± 0.05 (S.E.) mg/L) and Year 2 following restoration (0.16 ± 0.05 (S.E.) mg/L), with higher levels in Year 1 (0.30 ± 0.09 (S.E.) mg/L), Year 3 (0.35 ± 0.17 (S.E.) mg/L), and Year 4 (0.46 ± 0.18 (S.E.) mg/L). Again, Years 2 and 3 had above average rainfall, so ammonia concentrations do not seem to entirely correlate with climatic patterns. Most of the years with seemingly higher means (Years 1, 3, and 4) appear to be largely driven by fairly consistently high values (>1 mg/L) in one of the newly created Tomasini Slough side channels and, to a lesser extent, an existing channel that became tidal in the West Pasture.

The increase in ammonia detections between Passive and Full Restoration periods – and betweens Years 1 and Years 2, 3, and 4 -- could be entirely attributable to restoration-related changes: increase in ammonia following mineralization of decomposing organic matter and flushing of ammonia from soils into overlying waters with reintroduction of tidal and creek flows after the deliberate drawdown during construction. Oxygen and pH conditions within Project Area waters would appear sufficient to promote rapid conversion of ammonia into nitrates, with the possible exception of the two sampling sites with consistently high values, which are shallow creeks that may have reduced hydrologic exchange during low tides. In these areas, oxidation of the creek substrate during low tides or exposed conditions may encourage several biogeochemical processes, including conversion of organic matter and reduced iron and iron-sulfur compounds (pyrite) into humic acids and oxidized forms of iron and sulfur that are more acidic. These acidic compounds actually depress pH, which constrains nitrification and, thereby, reduces the conversion rate of ammonia into nitrates.

One interesting caveat to this hypothesis is that, during Year 1 of Full Restoration, ammonia detections increased in all of the Study Areas following restoration, even those distant from the Project Area. The number of detections in Reference Areas jumped 182% from 3.9% of the samples Pre-Restoration to 10.3% in Year 1 or WY 2009, while detection frequencies during Passive Restoration were roughly equivalent to Pre-Restoration (4.0%; Figure 10). Interestingly, while ammonia detections rose for Upstream Areas in Year 1, in subsequent areas, detections appeared appreciably lower than either Project or Reference Areas (Figure 10).

The number of ammonia detections significantly increased from Pre- and Passive Restoration to Full Restoration (Contingency, df=2, Chi-Square=5.96, P=0.05), with the number of detections totaling 11% through Year 4 post-restoration. Dissolved ammonia concentrations showed more of a weak statistical response to sampling year during Passive and Full Restoration (GLM, df=4, F=2.06, P=0.09), with Year 2 (0.11 ± 0.03 (S.E.) mg/L) differing principally from Year 4 (0.25 ± 0.05 (S.E.) mg/L; P=0.06). Levels during Passive Restoration and Years 1 and 2 seemed more similar to Year 4, ranging from 0.21 to 0.24 mg/L. while Year 3 was more intermediate (0.18 mg ± 0.04 (S.E.) mg/L).

The recent increase in ammonia detections within both the Project Area and Reference Areas – some of which are distant from the Project Area – suggests that the increases in ammonia detections documented after the Giacomini Wetlands were restored do not entirely result from restoration.

One possible explanation for the increase in ammonia detections in Year 1 may be the dry winter, which allowed tidal influence or the “salt wedge” to extend further upstream due to the lack of a strong countering force from freshwater flows. Recent research on salinity intrusion associated with sea level rise on the East Coast found that intrusion of even weakly saline waters into formerly freshwater tidal areas – tides affect rise and fall of water level, but do not affect salinity – mobilized ammonia into overlying waters, causing a net efflux or transport from the system. In these areas, ammonium, phosphate, and silicate fluxes increased by 20 to 38%; reduced iron fluxes increased by ~150%; methane fluxes decreased by 77%; and in situ organic carbon mineralization rates increased by ~110% (Joye et al. undated). Most of this increase probably results from cation exchange of the strongly ionic sodium chloride for ammonium (Craft et al. 2009), but ammonia may also be produced through increased mineralization of organic matter under tidal versus freshwater regimes. Salinity data collected in WY 2009 showed increases in salinity not only in the Project Area, which was expected, but in Reference Areas, so this supports the potential for increased upstream tidal influence to have caused biogeochemical changes that resulted in more frequent ammonia detections, at least during Year 1. In Years 2 and 3, wetter conditions drove down salinities below Pre-Restoration median levels by as much as 9-11 ppt, so higher ammonia detection frequencies in Years 2 and 3 relative to Passive Restoration periods are harder to explain.

Interestingly, despite occasional spikes in ammonia concentrations, only a few sampling locations prior to restoration exceeded the maximum concentration limit for unionized ammonia in estuarine waters of 0.16 mg/L (Parsons 2009). Some of these included East Pasture drainage ditches, where ammonia reached as 76 mg/L prior to restoration, and even one sampling location on Lagunitas Creek in April 2003, when total ammonia levels climbed as high as 13 mg/L. While ammonia was obviously detected in lower, but still relatively high, concentrations elsewhere in the dairy ranch, particularly in the East Pasture, temperature and/or pH did not climb high enough to encourage dissociation of ammonia into its unionized ion.

In general, ammonia detection frequencies between the Project Area (11.9%) and Reference Areas (11.1%) in Years 1 -4 of Full Restoration showed no statistically significant differences (Contingency, df=1, Chi-Square=0.04, P=0.84). However, mean dissolved ammonia concentrations did differ significantly between these Study Areas after restoration (GLM, df=1, F=4.05, P=0.05; log-transformed for analysis), with concentrations averaging 0.33 ± 0.07 (S.E.) mg/L in the Project Area and 0.19 ± 0.02 (S.E.) in Reference Areas. Differences were also significant between sampling years (GLM, df=4, F=3.63, P=0.013), with Year 2 (0.13 ± 0.03 (S.E.) mg/L) lower than Year 4 (0.35 ± 0.09 (S.E.) mg/L; P=0.008). These results would suggest that the Project Area is beginning to converge with Reference Areas in terms of nutrient levels, but still differs to some degree from natural marshes. In addition, short-term and long-term climatic conditions and other forces may cause system-wide changes in nutrient levels and patterns that will affect both Project and Reference Areas.

Phosphates and Phosphorous

Phosphates appeared to be driven more by biogeochemical processes than upstream loading, at least in most of the Project Area (Parsons 2009). While concentrations of phosphates prior to restoration were sometimes high during storm events – as was observed in Walker Creek and Lagunitas Creek -- they also showed peaks during spring and fall (ibid). These spring and fall peaks probably resulted from recirculation of phosphates from sediments into overlying waters when the upper sediment and bottom water layers became anoxic due to low oxygen levels at the soil-water interface, which can occur when plankton respiration rates increase substantially.

Prior to restoration, phosphate concentrations were highest in the Project Area and, specifically, in the East Pasture due to not only the proximity of sources such as cattle and septic-influenced groundwater, but also to agricultural management regimes that caused oxygen levels within ditch waters to frequently be low (Parsons 2009). Before the levees were breached, significant differences occurred between the frequency of detection between Study Areas (Chi Square Test, n=183, df=2, Chi-Square=9.29, p=0.010), with the number of detections disproportionately higher in the Project Area than in the other areas (ibid). Phosphates averaged an estimated 0.99 ± 0.16 (S.E.) mg/L in the Project Area Pre-Restoration compared to 0.23 ± 0.03 (S.E.) mg/L for Reference Areas and 0.12 ± 0.01 (S.E.) mg/L for Upstream Areas (Wilcoxon Score, n=346, df=2, p<0.001; ibid).

The East Pasture largely accounted for the disproportionate number of samples in which phosphates were detected Pre-Restoration (26%; Chi-Square Test, n=51, df=4, Chi-Square=25.47, p<0.001; ibid). It also accounted for 76% of the values recorded in the upper end of the detection range (0.79 – 9.4 mg/L), with detections in other subsampling areas typically falling below 0.79 mg/L (ibid). In the East Pasture, concentrations averaged an estimated 2.40 ± 0.33 (S.E.) mg/L Pre-Restoration, which was significantly higher than the means for the rest of the Project Area (excluding upstream sampling sites), which ranged from 0.15 mg/L (West Pasture) to 0.24 mg/L (Olema Marsh; ibid).

Low oxygen levels also probably accounted for the higher estimated average phosphate concentrations for Olema Marsh and for the higher estimated average concentration and loading rates during the summer for many of the Reference Areas such as Limantour and Walker Creek marshes. Phosphate levels within Reference Areas would also be influenced by the greater relative proximity of most of these systems to the ocean, where phosphorous is naturally high (Mitsch and Gosselink 2000, Day et al. 1989).

Following restoration, estimated mean phosphate concentrations in the Project Area appeared to drop significantly, decreasing almost 90% from 0.99 ± 0.16 (S.E.) mg/L during Pre-Restoration to 0.68 ± 0.37 (S.E.) mg/L during Passive Restoration and 0.10 ± 0.01 (S.E.) mg/L during Full Restoration (Wilcoxon, df=2, Chi-Square=80.9, P<0.0001). As of Year 3, estimated concentrations in the East Pasture – which had some of the highest pre-restoration levels -- had dropped from 2.40 ± 0.33 (S.E.) mg/L during Pre-Restoration to 1.69 ± 0.98 (S.E.) mg/L during Passive Restoration and 0.11 ± 0.16 (S.E.) mg/L during Full Restoration (Wilcoxon, df=2, Chi-Square=80.0, P<0.0001). Phosphate concentrations – and perhaps the frequency of phosphate detection – probably dropped to the discontinuation of active agricultural management and, with the removal of the levees, the improvement in oxygen levels within pasture waters. Following restoration, estimated mean phosphate concentrations in the Project Area ranged tightly between 0.10 ± 0.02 (S.E.) mg/L and 0.12 ± 0.02 (S.E.) mg/L in the first three years and then dropped slightly in Year 4 to 0.06 ± 0.01 (S.E.) mg/L. In comparison, within Reference Areas, estimated concentrations declined 61% from 0.23 ± 0.03 (S.E.) mg/L during Pre-Restoration to 0.09 ± 0.01 (S.E.) mg/L during both Passive and Full Restoration (Wilcoxon, df=2, Chi-Square=48.3, P<0.0001).

Total phosphorous levels were also assessed within Study Areas. Total phosphorous incorporates both free and bound forms of phosphorous, unlike phosphates, which are only in dissolved form. In general, total detections of phosphorous in Project Area waters decreased from 62.9% during Passive-Restoration to 39.5 – 41.0% in Years 1 and 2, climbing back up to 68.9% in Year 3 (Contingency, df=3, Chi-Square=11.8, P=0.008; Figure 11). Interestingly, a similar pattern occurred in Reference Areas (Figure 11). For Reference Areas, total phosphorus was detected approximately 75.6% of the sampling events during Passive Restoration, with detections falling to between 37.9- 48.3% in Years 1 and 2 and then climbing back up to 75.0% in Year 3 (Contingency, df=3, Chi-Square=14.6, P=0.002; Figure 11). The highest number of total phosphorous detections, though, appeared to occur in Upstream Areas (Figure 11), which is not surprising as total phosphorous is often bound to sediment that is mobilized mostly during storm events and, therefore, is likely to be higher in creek areas. Due to budgetary constraints, total phosphorous was not sampled for all the sampling periods in Year 4, so that data is not incorporated into this analysis.

Estimated total phosphorous concentrations in the Project Area dropped from 0.99 ± 0.13 (S.E.) mg/L during Passive Restoration to between 0.14 ± 0.01 (S.E.) mg/L in Year 2 and 0.22 ± 0.06 (S.E.) mg/L in Year 1 (Wilcoxon, df=3, Chi-Square=11.9, P=0.008). In Reference Areas, estimated phosphorous concentrations also dropped between Passive Restoration (0.18 ± 0.03 (S.E.) mg/L) and Years 1 (0.05 ± 0.04 (S.E.) mg/L) and 2 (0.08 ± 0.03 (S.E.) mg/L), but climbed back up in Year 3 (0.18 ± 0.06 (S.E.) mg/L; MLE, df=3, Chi-Square=15.1, 0.001<P<0.01). While total phosphorous might be expected to increase during storm events, when sediment loads are greatest, this pattern was not necessarily reflected in the data, which showed pulses in total phosphorous during low flow, as well as high flow, sampling events. A comparison of total phosphorous and orthophosphate data for Year 3 alone showed very low correlation between these two phosphorous parameters (Pearson Correlation=0.016, P=0.88).

As with last year, median phosphate concentrations did not differ between the Project Area (0.10 ± 0.01 (S.E.) mg/L) and the Reference Areas (0.09 ± 0.01 (S.E.) mg/L; GLM, df=1, F=0.43, P=0.51). In addition, through at least Year 3, total phosphorous detections during post-restoration between the Project Area (50.0%) and Reference Areas (53.5%) did not differ significantly (Contingency, df=1, Chi-Square = 0.254, P=0.614). Estimated total phosphorous concentrations also appeared similar through Year 3 between the Study Areas, averaging 0.18 ± 0.02 (S.E.) mg/L for the Project Area and 0.17 ± 0.02 (S.E.) mg/L for Reference Areas (Wilcoxon, df=1, Chi-Square=0.14, P=0.71). Therefore, the Project Area appears to converging further with conditions in with Reference Areas, at least in terms of phosphate and total phosphorous levels, however, more data will be needed to make any definitive conclusions, particularly as the restored marsh is still actively evolving. The same restoration-related factors that can affect nitrate and ammonia levels can also drive up phosphates, i.e., breakdown and mineralization of decaying pasture organic matter. In addition, frequent to continuous inundation of former pasture areas may create an anoxic soil interface that encourages flux of agriculturally related phosphates from soils into overlying waters.

Some caveats must be noted for these results. Analytical chemistry methods were changed between Pre-Restoration and subsequent sampling periods or treatments, with measurement of total dissolved phosphates being changed to measurement of orthophosphates. Also, the method detection limit decreased greatly, which negates our ability to use Contingency Tables to evaluate changes in the number of detections between treatments. Total dissolved phosphates typically incorporates polyphosphates, as well as orthophosphates, so orthophosphates would be considered to represent a smaller fraction of the dissolved phosphorous component, although polyphosphates are unstable and will eventually convert over time to Orthophosphate, particularly in low oxygen waters (Murphy 2007). A comparison of orthophosphate and total dissolved phosphates for several sampling periods during Passive Restoration when both were measured showed typically 94 to 99% correlation, although, during one sampling event, correlation was as low as 48%: as samples were collected in different jars and sent to different laboratories, the dynamic and extremely variable nature of natural waters, which can change rapidly from moment to moment, does not make the latter result extremely surprising.

Pathogens A Major Issue in Project -- and Reference – Areas, but Levels in Project Area Dropped Dramatically After Restoration

In general, pathogens represent one of the major water quality issues facing Tomales Bay. While seemingly pristine, the Bay and its surrounding watershed generate a considerable volume of pathogen indicator bacteria, total and fecal coliform, because of the large amount of land in agricultural use, leaking septic systems in the many rural residential communities perched on the Bay's edge, and other factors such as bilge discharge from boats. With Giacomini Ranch supporting a considerable number of dairy cattle during its operation, the Project Area was certainly located in an area where it could have had maximum impact on downstream water quality.

Prior to restoration, the Project Area had substantially higher estimated median concentrations of fecal coliforms (1,600.9 mpn/100ml) than the Reference Areas (72.0 mpn/100 ml), although seeming differences with Upstream Areas (705.6 mpn/100 ml) might have been obscured to some degree by high variance in the data (MLE Regression, df=2, Chi-Square=98.5, $p<<0.0001$; Parsons 2009). Not surprisingly, the heavily managed East Pasture had significantly higher estimated geometric means or medians (6,298.8 mpn/100 ml) Pre-Restoration than most of the other sub-sampling areas, with the possible exception, from a statistical standpoint, of Olema Marsh (1,821.4 mpn/100 ml; ibid). Estimated geometric means or medians for all other subsampling areas ranged between 356.9 mpn/100 ml for downstream Lagunitas Creek to 1,131.7 mpn/100 ml for the West Pasture (ibid).

In terms of compliance with Basin Plan or TMDL standards, prior to restoration, more than 95% of all samples collected from the Project Area and Upstream Areas exceeded objectives for shellfish harvesting and municipal water supply of 14 and 20 mpn/100 ml respectively (Parsons 2009). Approximately 78% exceeded contact water recreation standards of 200 mpn/100 ml, and 36-47% of the values actually were higher than 2,000 to 4,000 mpn/100 ml, the standards for non-contact water recreation (ibid). Lagunitas Creek exceeded the TMDL standard of 200 mpn/100 ml during 72% of the sampling events and the 90th percentile standard of 400 mpn/100 ml 58% of the time, with the overall geometric mean and 90th percentile estimated at 584.6 mpn/100 ml and 6,146.8 mpn/100 ml, respectively (ibid). The TMDL load-based allocation of 95 mpn/100 ml set for Green Bridge location on Lagunitas Creek was never met during the Pre-Restoration study period. In comparison, only 34% of Reference Area samples exceeded contact water recreation standards, and less than 12% exceeded non-contact water recreation standards (ibid).

Following restoration, the estimated geometric mean or median fecal coliform concentrations decreased significantly in the Project Area, dropping 93% from 1,600.9 mpn/100 ml during Pre-Restoration to 107.0 mpn/100 ml during Full Restoration (MLE, df=2, Chi-Square=97.0, P<<0.0001; Figure 12). Estimated median concentrations during Passive Restoration fell in-between those of Pre- and Full Restoration (919.9 mpn/100 ml) and varied significantly from Full Restoration (Z test<0.0001; Figure 12). Coliform levels, which had already declined somewhat during Passive Restoration, dropped sharply again immediately after restoration in Year 1 (median=90.4 mpn/100 ml). Median concentrations appeared to climb slightly in both Years 2 and 3 to 141.3 and 134.1 mpn/100 ml, respectively, but dropped again in Year 4 (74.0 mpn/100ml).

Not surprisingly, large decreases were recorded in the once heavily managed East Pasture, with estimated median levels dropping more than 78-98% from 6,298.8 mpn/100 ml during Pre-Restoration to 1,385.3 mpn/100 ml during Passive Restoration and to 81.0 mpn/100 ml during Full Restoration (MLE, df=2, Chi-Square=66.4, P<0.0001). After restoration, levels in the East Pasture varied from 64.1 mpn/100 ml in Year 1 to 119.7 mpn/100 ml in Year 2; 135.1 mpn/100 ml in Year 3; and 42.1 in Year 4. Estimated mean concentrations in the West Pasture also dropped by more than 95% from 1,131.7 mpn/100 ml Pre-Restoration to 655.4 mpn/100 ml during Passive Restoration and to 79.2 mpn/100 ml during Full Restoration (MLE, df=2, Chi-Square=34.9, P<0.0001). After restoration, levels have averaged 48.7 mpn/100 ml in Year 1; 88.2 mpn/100 ml in Year 2; 95.2 mpn/100 ml in Year 3; and 67.7 mpn/100 ml in Year 4.

Decreases in Olema Marsh also appeared substantial after restoration. Median concentrations in Bear Valley Creek at the downstream boundary of the Project Area fell from 1,923.55 mpn/100 ml prior to restoration to 460.7 mpn/100 ml after restoration (MLE, df=1, Chi-Square=4.33, 0.05>P>0.02). No actions were taken in Olema Marsh during Passive Restoration, so it is more appropriate to evauate only pre- and post-restoration for this Study Area. .

Estimated median levels in Reference Areas were lower in WY 2009 or Year 1 post-restoration (median=21.0 mpn/100 ml) than in the years prior to restoration (72.0 mpn/100 ml; MLE, df=3, Chi-Square=7.56, 0.10>p>0.05). This suggested that lower concentrations in all Study Areas in WY 2009 might have been affected to some degree by the dry winter, decreased precipitation, and reduced pollutant inflow. This is supported by the fact that, in Year 2 or WY 2010, coliform levels generally increased in both the Project Area and in the Reference Areas, with Reference Areas reaching almost pre-restoration levels of 70.6 mpn/100 ml. WY 2010 was much wetter than WY 2009. However, levels in subsequent year did not support this hypothesis, as levels during a wetter Year 3 were actually lower (46.1 mpn/100 ml) than the drier Year 4 (68.7 mpn/100 ml). Unlike the Project Area, no statistically significant difference was apparent between restoration sampling periods for Reference Areas (MLE, df=2, Chi-Square=2.42, P>0.20).

The dramatic declines in fecal coliform concentrations in the Project Area following restoration, even during wetter periods, are also evident in changes in the frequency of exceedance of Basin Plan or TMDL standards. Exceedance of municipal water supply thresholds of 20 mpn/100 ml dropped from 95% of all samples collected in the Project Area Pre-Restoration to between 80% and 89% of all samples collected during Years 1 – 4 of Full Restoration, respectively. Approximately 38% of samples from the post-restoration period exceeded the contact water recreation standards of 200 mpn/100 ml, compared to approximately 78% Pre-Restoration, at least a 51% decrease. Only 6% of samples collected after levees were breached exceeded 2,000 mpn/100 ml, the standards for non-contact water recreation, whereas 47% exceeded before levee removal. In comparison, the number of samples exceeding municipal water supply thresholds within Reference Areas remained pretty consistent between sampling periods at approximately 70%. However, the frequency of exceedance of contact water recreation standards (200 mpn/100 ml) in Reference Areas decreased from 37% during the Pre-Restoration period to 30% during the Passive Restoration period and 20% during the Full Restoration period. Similarly, the number of samples exceeding non-contact standards dropped from 12% during the Pre-Restoration period to <5% during the Passive Restoration period and <2% during the Full Restoration period.

One of the established sites for fecal coliform monitoring in the TMDL program is Lagunitas Creek at the Green Bridge, just upstream of the restoration period. The restoration project would not be expected to directly influence fecal coliform concentrations at this location, because it is upstream of the restoration project, and fecal coliform levels are strongly associated with watershed loading. However, there may be indirect effects due to changes in hydrologic circulation and other factors. Coliform levels at the upstream end of the Project Area boundary on Lagunitas Creek at the Green Bridge remained roughly similar to Pre-Restoration conditions, with the TMDL standard of 200 mpn/100 ml being exceeded approximately 60% of the time, compared to 72% of the time prior to the restoration period. The 90th percentile of 400 mpn/100 ml standard was exceeded approximately 44% of the sampling periods during the post-restoration period, as opposed to 58% of the time Pre-Restoration. Exceedances of the 95 mpn/100 ml TMDL load-based allocation for the Green Bridge sampling site dropped somewhat from 100% during Pre-Restoration to 76% after restoration. The overall geometric mean and 90th percentile in the post-restoration period was estimated at 301.2 mpn/100 ml and 2,625.0 mpn/100 ml.

Based on the difference fecal coliform patterns in Project and Reference Areas after restoration, it appears that changes in Project Area concentrations can be at least partially ascribed to the restoration, although changes in precipitation and pollutant inflow in drier and wetter years must be taken into account. Reduced rainfall causes an overall drop in pollutant mobilization or loading, but, based on the lack of strong correlation between median levels and annual precipitation totals, other factors are influencing levels, as well, including perhaps distribution or pattern of rainfall during the year, correlation with sampling events, and point source loading.

However, despite some similarity in trends between the Project Area and Reference Areas, estimated median coliform levels during Full Restoration differed between these two (MLE, df=2, Chi-Square=30.5, P<0.0001), with medians being 107.0 mpn/100 ml for the Project Area and 49.0 mpn/100 ml for Reference Areas. Again, as the Project Area receives more surface water and groundwater (influenced by septic) than Reference Areas, these two Study Areas may never totally converge for this particular parameter.

Loading Rates in Project Area Increase Slightly as Expected After Restoration Due to Hydrologic Reconnection of Diked Former Pasture Lands

Despite high concentrations in the Project Area prior to restoration, loading rates for the Giacomini Ranch and Olema Marsh Pre-Restoration were usually lower or only slightly higher than Reference Areas (Parsons 2009). This trend reversal resulted from the fact that the East Pasture – where concentrations were highest – essentially contributed very little to downstream loading, because it was diked (ibid). The only potential for loading from the East Pasture came during moderate to large storm events when waters in the pasture overtopped the levees or when the Giacominis occasionally pumped ditch waters into Lagunitas Creek (ibid). However, even if the East Pasture had been operated as a muted tidal unit, the volume of water and, subsequently, loading that these ditches and sloughs could have contributed to downstream flow would have been relatively insignificant (between 0.1 and 1.15 mg/s for nitrate loading), based on rates estimated using average discharge for similarly sized creeks in the adjacent Undiked Marsh: with diking of both Lagunitas and Tomasini Creeks, the East Pasture had no other source watersheds to increase flow and loading volumes (ibid).

Prior to restoration, then, loading rates were generally highest in Upstream Areas, which included sampling locations on the upstream perimeter of the Project Area on Lagunitas, Tomasini, Bear

Valley, and Fish Hatchery Creeks (Parsons 2009). There were some exceptions. For example, for fecal coliform, estimated loading rates for the Project Area (mean=249,389 mpn/s) were lower than Upstream Areas (mean=3.86 million mpn/s), but higher than Reference Areas (mean= 60,094.1 mpn/s; ibid). Conversely, Reference Areas had the highest loading rates for phosphates (0.15 mg/s), with rates for the Project Area (0.03 mg/s) and Upstream Areas (0.06 mg/s) considerably lower, which, as discussed earlier, may relate to the more substantial marine influence in these areas (ibid).

As with concentrations, estimated median loading rates Pre-Restoration were considerably smaller than mean loading rates, showing the influence of pulses during the winter or wet season sampling events (Parsons 2009). One of the clear findings from our study is the close relationship between rainfall, run-off, streamflow, and loading. While these relationships were not always distinct enough to be linear, with some exceptions, most of the high loading events occurred during winter or wet-season sampling events, with the highest values usually occurring during storm events. The importance of storm events to downstream loading is evident in the disparity between mean (10.11 mg/s) and median (0.66 mg/s) instantaneous loading rates for nitrates on Lagunitas Creek: During an April 2006 storm, rates reached as high as an estimated 220 mg/s (ibid).

During storm events, nitrate concentrations in Lagunitas Creek can reach as high as 2.0 – 2.5 mg/L, which is notably higher than the peak nitrate concentrations of approximately 1.5 mg/L (24*u*M) documented off the Point Reyes coast that is potentially exported into Tomales Bay during upwelling events (Largier et al. 2006, Wilkerson et al. 2006). While these upwelling events may influence nutrient conditions in the outer portion of Tomales Bay during the summer, when streamflow is lowest, the likelihood that these nutrient reach the inner portion of Tomales Bay is reduced by the fact that, during the summer, hydrologic exchange between the outer and inner portions of the Bay becomes infrequent, occurring only every 120 days, due to changes in estuarine circulation patterns (Hollibaugh et al. 1988) Research on other agricultural watersheds has also documented the highest export of nutrients and pathogens in stormflow, with levels generally higher in the wet season than the dry season (Vanni et al. 2001, Lewis and Atwill 2007). Ironically, storms have been the least sampled in Tomales Bay due to inherent planning and logistical difficulties, however, we have been increasing efforts to capture storm events in the monitoring record.

Because the levees essentially precluded or minimized export of pollutant loads from the ranch pastures, with full levee removal, the contribution of the Project Area to downstream loading would be expected to increase, even if concentrations within the Project Area dropped dramatically. For example, for fecal coliform, estimated geometric mean or median loading rates jumped 274% from 57.5 mpn/s during Pre-Restoration to 242.8 mpn/s during Passive Restoration and 215.2 mpn/s during Full Restoration (MLE, df=2, Chi-Square=7.39, 0.05>P>0.02), with primary differences being between pre- and post-restoration periods (Z test=0.008; Figure 13). Trends were slightly different in Reference Areas. For Reference Areas, estimated median fecal coliform loading rates appeared to drop 36% from 98.3 mpn/s during Pre-Restoration to 23.3 mpn/s during Passive Restoration before climbing to 63.0 mpn/s during Full Restoration (MLE, df=2, Chi-Square=5.92, 0.10>P>0.05), with Full Restoration levels weakly differing from Passive Restoration ones (Z test=0.07; Figure 13).

For nitrates, loading increased between Pre-, Passive, and Full Restoration (GLM, df=2, F=3.22, P=0.04, log-transformed for analysis), with estimated means climbing from 0.60 ± 0.42 (S.E.) mg/s pre-restoration to 1.17 ± 0.65 (S.E.) mg/s during Passive Restoration and 1.44 ± 0.49 (S.E.) mg/s after restoration, with Pre-Restoration differing principally from Full Restoration ones (P=0.03). Conversely, while nitrate loading rates appeared to increase, as well, in Reference Areas between at least pre- and passive-restoration periods, the rates were statistically equivalent between these periods, averaging 0.51 ± 0.11 (S.E.) mg/s Pre-Restoration; 0.84 ± 0.70 (S.E.) mg/s during Passive Restoration, and 0.61 ± 0.38 (S.E.) during Full Restoration (GLM, df=2, F=1.60, P=0.20, log-transformed for analysis).

Ultimately, as discussed in earlier sections, the Project Area may not converge with conditions present in Reference Areas. The Project Area bears the full brunt of approximately 66% of the freshwater – and pollutant – inflow to Tomales Bay. While the Undiked Marsh also falls in this system, it is further downstream, and pollutants are more likely now to have been intercepted by the newly restored flood- and marshplains of the Project Area. Walker Creek does receive the full of Walker Creek flows, but this subwatershed -- and potentially its pollutant load – is smaller than that of Lagunitas Creek, although it also has its pollution issues. However, despite these factors, conditions appear to becoming more similar between Study Areas. During the first four years after restoration, median fecal coliform loading rates in the Project Area (215.2 mpn/s) were significantly higher than those in Reference Areas (63.0 mpn/s; MLE, df=1, Chi Square=24.5, P<0.0001), and loading rates also varied to some degree between some of the post-restoration years among Study Areas, pointing to the relationship between climatic patterns and pollutant inflow (Z-test, all P<0.10) Nitrate loading rates also differed significantly between the restored Project Area (1.44 ± 0.49 (S.E.) mg/s) and Reference Areas (0.61 ± 0.38 (S.E.) mg/s; GLM, df=1, F=9.38, P=0.002, log-transformed for analysis) although there were no statistically significant differences among Study Areas between post-treatment years unlike fecal coliform loading (GLM, df=3, F=1.66, P=0.175).

Restored Wetlands' Potential to Trap Downstream Pollutant Loads Still Evolving

Because of being extensively leveed prior to restoration, the Project Area was not expected to provide much in the way of downstream reduction in either concentrations or loading of nutrients or pathogens (Parsons 2009). In general, floodplain systems are most effective at removing particulate forms of nutrients and other pollutants, because emergent vegetation "traps" the sediment or organic matter and removes it from water sheetflowing across the floodplain or marshplain surface. Pollutants can also be trapped within creek channels and bays by physical forces related to fluvial and estuarine sediment transport and circulation processes. Sediment laden with nutrients, organic matter, and pollutants are likely to deposit in areas where the creek gradient flattens or velocities decrease sharply.

While this type of analysis is important to understanding wetland health and restoration success, obtaining an accurate understanding is confounded by a number of factors and may not be possible using our sampling approach. Water quality data is highly variable, and this high variability, coupled with low sample size, may largely obscure any upstream-downstream patterns. Also, almost none of the creeks or water bodies, including Lagunitas, Fish Hatchery, Bear Valley, and even those in the East Pasture, are what would be considered "closed" systems. Inflow from small drainages, groundwater, and non-point source discharge enters these systems in between the upstream and downstream sampling points. Groundwater inflow, in particular, is difficult to characterize in terms of loading due to its diffuse nature, but, based on results of sampling of these areas over the years, groundwater and non-point source discharges could be contributing greatly to pollutant loading. This type of analysis requires that all sources of surface water inflow be accurately accounted for to reliably estimate both inputs and outputs. Lastly, one grab sample may not accurately capture the cross-sectional loading profile, particularly for wider creeks.

Some preliminary analysis of downstream reductions in pollutants was conducted for nitrate and fecal coliform loading rates prior to restoration (Parsons 2009). Fecal coliform concentrations and loading showed no statistically significant pattern of downstream reductions for any of the Project Area creeks, although there was high variability in the data (Parsons 2009). Median pathogen concentrations and/or loading rates actually increased downstream in some areas, including Fish Hatchery Creek and Bear Valley Creek (ibid). For both of these systems, this suggests that there are some additional inputs other than the upper portions of Fish Hatchery and Bear Valley Creek watersheds, such as wildlife use or septic-influenced surface water and groundwater flowing from the adjacent developed portion of Inverness Ridge into the west end of the marshes (ibid). Despite the fact that soluble nutrients such as nitrates are the least effectively trapped pollutants by floodplain systems, nitrates did show some downstream reductions prior to restoration for many of the creeks, including Fish Hatchery Creek, Tomasini Creek, and Bear Valley Creek, all of which were leveed or impounded to some degree (Parsons 2009).

Following restoration in 2008, the Giacomini Wetlands began a new process of evolution and can be expected to take time to reach their full nutrient trapping potential due to the loss of vegetation and larger expanse of bareground during the conversion of pastureland to marsh. Some preliminary evaluations of fecal coliform data collected in the first year after showed no statistically significant differences in estimated fecal coliform loading between upstream and downstream sampling sites in the first year of Full Restoration, although most creeks did appear to show lower estimated geometric means or medians for pathogen levels and loading downstream than upstream. One exception to this was Bear Valley Creek in Olema Marsh, where estimated median loading, if not estimated median concentrations, actually appeared to be higher downstream than upstream, although differences were not strongly significant (MLE, df=1, Chi-Square=2,83, 0.10>P>0.05).

In Year 2, both average and median instantaneous nitrate loading rates appeared to be lower downstream than upstream on Fish Hatchery Creek and Tomasini Creek, but not on Bear Valley Creek, although none of the analyses were statistically significant (Paired t-tests and Mann-Whitney, all P>0.110) In contrast to nitrate loading, fecal coliform loading appeared generally higher downstream than upstream, with the exception of average (arithmetic mean) fecal coliform loading on Tomasini Creek, where downstream instantaneous loading rates appeared lower However, as with nitrate loading, none of these differences were statistically significant (Paired t-tests and Mann-Whitney, all p>0.116).

Drawing definitive conclusions from these data are difficult, given the issues discussed above. For those reasons, further analyses of upstream-downstream loading were not conducted in Year 3. A truly valid understanding of the newly restored wetland’s role in improving downstream water quality will require a more intensive, research-type approach with sampling of all input sources at multiple locations in the channel during storm events of varying magnitudes. What conclusion can be drawn from the preliminary data analysis is that the Giacomini Wetlands is a very complicated hydrologic system, and it would be difficult even with a research-type approach to tease out how much pollutant reduction the restored wetlands are responsible for given the numerous surface water, groundwater, and non-point source discharges into the marsh.

Conclusions

In the environmental assessment document (NPS 2007), the impact analysis section predicted short-term negative impacts resulting from the conversion of pastureland to marsh, with long-term benefits for water quality conditions within the former Giacomini Dairy Ranch, as well as for downstream water quality and the health of Tomales Bay. In general, the speed with which conditions improved within the Project Area for variables such as dissolved oxygen, nitrates, and fecal coliform concentrations far exceeded our expectations. In addition, some of the expected problems have not materialized such as extremely high turbidity levels associated with tidal reworking of now barren soils and episodes of hypoxia or anoxia due to biological oxidation demand associated with breakdown of organic matter (Table 1).

With some exceptions, water quality parameters have shown significant, positive improvements in conditions between Pre- and Full-Restoration phases (Table 1). Dissolved oxygen levels increased 14%, while nitrate, ammonia, phosphate, phosphorous, and fecal coliform levels decreased at least 23%, with some of these parameters falling quite substantially (90%). Somewhat expectedly, nitrate and fecal coliform loading and turbidity have increased since restoration, although the latter was not as dramatic as was anticipated (49%). Loading was certain to increase, given that the ranch was largely diked before and not contributing fully to pollutant loading to Lagunitas Creek except during extreme flood stages.

Table 1. Similarity between the Project Area and Reference Areas (natural marshes) in water quality variables before and after restoration and changes in parameters within the Project Area before and after restoration. CV refers to coefficient of variation, with the best comparison variables having a comparatively low CV (0.2 or less) in natural systems.

Parameter	Similarity to natural marshes before restoration	CV of natural marshes	Expected Change in Project Area *Short-Term*	Expected Change in Project Area *Long-Term*	Change in Project Area since restoration	Change in natural marshes since restoration	Similarity to natural marshes after restoration
Salinity (ppt)	≠	0.54	↑	↑	↑70%	↓24%	≠[1]
Dissolved oxygen (mg/L)	≠	0.37	≈/↓	↑	↑14%	=	=
p.H.	=	0.06	≈/↓	↑	↓5%	↓5%	≠
Temperature (° C)	≠	0.31	↑	↑	↓6%	↓11%	=
Nitrates	≈	0.78	≈/↑	↓	↓64%	↓40%	= (median only)
Total Amm. detections	=	0.54	≈/↑	↓↓	↓23%	↑182%	=
Phosphates	≠	0.61	≈/↑	↓	↓90%	↓61%	=
Fecal Coliform	≠	>>1.0	↓	↓↓	↓93%	=	≠
Nitrate Loading	≠	NA[1]	↑↑	↑	↑140%[2]	=	≠
Fecal Coliform Loading	≠	NA[1]	↑	≈/↑	↑274%[2]	=	≠
Turbidity	=	>>1.0	↑↑	↓	↑49%	=	=

[1] Not evaluated statistically

[2] Relative to leveed conditions in which outflows eliminated, infrequent, or highly regulated by tide gates

As might be expected, salinity in the Project Area climbed 70% relative to the diked dairy ranch conditions due to increased tidal influence. This same influence was expected to increase temperatures relative to the diked dairy conditions, however, temperatures unexpectedly dropped 6%, probably because residence time of waters decreased, and exchange with other water bodies increased, even if estuarine waters are often warmer than freshwater ones. Over the short term, pH was expected to decrease or remain the same, with the acid-producing effects of oxidation of organic matter and production of acids being countered to some degree by introduction of higher pH tidal waters. Not surprisingly, then, the pH within the restored wetland has declined 5% since the levees were breached.

In addition to a significant change relative to Pre-Restoration conditions, the other way in which the restored wetland can be evaluated in terms of water quality improvement is the degree of similarity in water quality conditions between the Project Area and Reference Areas. After only a short time (four years), most of the parameters, including temperature, dissolved oxygen, ammonia, phosphates, phosphorous, and seemingly at least median concentrations of nitrates were actually statistically equivalent to Reference Areas (Table 1). Even turbidity levels in the Project Area showed no statistical difference with those in Reference Areas, despite the fact that they had increased relative to Pre-Restoration conditions in the Project Area. Some of these parameters – temperature, dissolved oxygen, and phosphates -- differed substantially from Reference Areas prior to restoration, so these results would suggest progress in restoring natural conditions. Others were similar prior to restoration and have remained so following the levee breach: turbidity, ammonia, and nitrates. The only parameter that continued to differ negatively from Reference Areas was fecal coliform, even though levels had dropped substantially from Pre-Restoration conditions. Nitrate and fecal coliform loading also differed, but, during the pre-restoration period, loading was actually lower in the Project Area than in natural marshes, and now it is higher. The pH was the only variable that was actually equivalent to natural marshes before the levees were breached and has subsequently become lower than in tidally influenced Reference Areas.

In evaluating changes in the restored wetland, comparisons with trends in Reference Areas prove quite valuable. For some variables such as dissolved oxygen, turbidity, and loading of nitrates and fecal coliform increased in the Project Area, while remaining roughly the same in natural marshes. Fecal coliform levels decreased in the Project Area, but remained similar to pre-restoration conditions in Reference Areas. However, in some instances, changes were also occurring in natural marshes. In most of these cases, the trajectory of these changes was similar between Study Areas. For example, a short-term decline in Project Area pH was anticipated and has occurred, with pH dropping 5%, but pH also declined 5% in Reference Areas. Conversely, while temperature, nitrates, and phosphates were expected to increase over the short-term after restoration in the restored wetland, they actually decreased, however, they did so, as well, in natural marshes. In some instances, the trends in Reference Areas have been contrary to that of the Project Area. Since restoration, salinity has increased 70% in the Project Area, but decreased 24% in Reference Areas, and ammonia detections have dropped 23% in the restored wetland, but climbed 182% in Reference Areas.

These comparisons are important, because they help in evaluating whether changes in the Project Area are related to restoration or potentially other factors or both. In situations where similar trends occurred between the two Study Areas – pH, temperature, nitrates, and phosphates -- restoration cannot be considered the only factor affecting post-restoration water quality conditions. In most of these cases, climatic patterns appear to be influencing water quality on a watershed scale. Following restoration, there have been two wet years (Years 2-3) and two average rainfall years (Years 1 and 4), and rainfall volume and distribution patterns may have affected some of the parameters such as temperature, nitrates, and possibly even pH, as pH of some freshwater sources such as groundwater can on the lower end of circumneutral (Parsons 2009). Climatic factors may play a role even in instances where trends are dissimilar, such as salinity and ammonia. Wet years in Years 2 and 3 may have driven down average salinities post-restoration throughout the watershed, but, in the Project Area, these decreases were countered to a large degree by the higher average salinity of tidal waters flowing into the restored wetland.

The situation with ammonia and pH appears a bit more complicated than can be explained simply by climatic variability. It should be noted that ammonia detections not only increased in Reference Areas during the post-restoration sampling period, but they also increased in the Project Area relative to Passive Restoration, if not Pre-Restoration, levels. During Year 1 post-restoration, one possible explanation for this increase in ammonia detections may have been the dry winter, which allowed tidal influence or the “salt wedge” to extend further upstream due to the lack of a strong countering force from freshwater flows. Recent research on salinity intrusion associated with sea level rise on the East Coast found that intrusion of even weakly saline waters into formerly freshwater tidal areas – tides affect rise and fall of water level, but do not affect salinity – mobilized ammonia into overlying waters, causing a net efflux or transport from the system. Most of this increase probably results from cation exchange of the strongly ionic sodium chloride for ammonium (Craft et al. 2009), but ammonia may also be produced through increased mineralization of organic matter under tidal versus freshwater regimes. Salinities were generally higher in WY 2009. However, ammonia detections remained high in Years 2 and 3 relative to Pre-Restoration conditions were harder to explain, even thought they were both wet years, and so freshwater should have pushed back the “salt wedge.” Ammonia detections do tend to show peaks in summer, when oxidation of the creek substrate during low tides or exposed conditions may encourage several biogeochemical processes, including conversion of organic matter and reduced iron and iron-sulfur compounds (pyrite) into humic acids and oxidized forms of iron and sulfur that are more acidic. These acidic compounds actually depress pH, which constrains nitrification and, thereby, reduces the conversion rate of ammonia into nitrates.

Decreases in pH, by necessity, raise concerns about possible impacts from ocean acidification. Since sampling was initiated, pH has steadily declined in the Project Area, dropping overall from 7.60 during Pre-Restoration to 7.30 during Passive Restoration and 7.23 during Full Restoration despite the increase in higher pH tidal waters and expected decrease in the influence of lower pH groundwater inflow on the restored system. Some of this decrease may be attributable to the restoration such that the breakdown of organic matter is generating more humic acids. However, as noted earlier, pH has not only declined 5% in the Project Area, but also in Reference Areas. In Reference Areas, pH dropped from a median of 7.62 during the Pre-Restoration and Passive Restoration sampling periods to 7.33 after restoration. Median pH declined more sharply in the Undiked Marsh and Limantour Marsh than in Walker Creek Marsh. The dramatic decreases in median pH in the Undiked Marsh and Limantour Marsh since WY 2007 could potentially result from the fact that, in these systems, upstream areas have been restored, and restoration is affecting pH of downstream marshes, as well as the Project Areas. Alternatively, pH in both watersheds may be more affected by climatic patterns or even a combination of these factors.

There are some parallels with other data recently collected in Tomales Bay. Ten of the LMER Tomales Bay sampling stations that were monitored extensively between 1987 and 1995 were monitored again for a few years by University of California, Davis, researcher Ann Russell. Russell and her colleagues found strong similiarity between the datasets for most of the water quality parameters, except for pH and dissolved organic (DOC) and inorganic carbon (DIC). The pH of Tomales Bay during the recent sampling period appeared to be as much as 0.25 pH units than that recorded in the late 1980s-1990s (A. Russell, UC Davis, *pers. comm.*). While changes in pH invariably lead to questions about the effect of ocean acidification on pH of tidal waters flowing into estuaries, Russell noted that the change observed in Tomales Bay was too large to be attributable to dissolution of CO^2 from the atmosphere into estuarine waters. However, not all carbon inputs into the estuary come from the atmosphere, and the difference could be potentially related to changes in DOC and DIC inputs from marine and terrestrial sources (ibid). Also, the LMER sampling occurred during a relatively dry decade, so it’s possible that higher rainfall volume may have also lowered pH relative to levels observed during that previous sampling period (J. Largier, UC Davis, *pers. comm.*). However, even if these pH changes are unrelated to ocean acidification, it does not rule out that we may begin to see changes related to climate change in future years, although pH in estuaries is normally more highly variable than that in oceans even without the influence of climate change.

Another non-restoration related factor that may affect water quality conditions in the Project Area is non-point source discharge. These systems are not closed and receive inputs of pollutants from smaller drainages, groundwater inflow, and non-point source discharge. Most of these sources would be expected to vary similarly to the marshes such that loading is more substantial during higher rainfall periods, however, this is not always the case. Nitrate, particularly average nitrate levels, within the restored wetland appear to be strongly affected by a non-point-source discharge site in Point Reyes Station that has high levels of nitrates throughout the year, although winter inputs are often highest. There are also occasional spikes in fecal coliform levels. These waters run downslope into a created freshwater marsh within the restored wetland, thereby elevating pollutant inflow into this habitat that was created for federally listed species such as California red-legged frog (*Rana draytonii*): this marsh is a closed water body with no or very little opportunity for hydrologic exchange.

Ultimately, restoration appears to be the primary factor driving changes in levels of salinity, dissolved oxygen, turbidity, ammonia, and fecal coliform and loading rates of nitrates and fecal coliform in the Project Area since the levees were breached. However, the situation is not as clear cut for some of the other variables such as pH, temperature, nitrates, and phosphates, levels of which dropped in both the Project and Reference Areas between the pre- and post-restoration sampling periods. In the case of pH, the rate of decline was identical between the Study Areas, strongly suggesting that external factors such as precipitation and variation in freshwater inflow may be more influencing pH than any restoration-related factors such as release of acids from biological or biogeochemical processes associated with decomposition of organic matter or oxidation of soils. The same appears true appears true for temperature. However, the differences in the magnitude of change between the Project and Reference Areas for variables such as nitrates and particularly phosphates suggests that both restoration and climatic factors may be playing a role in shaping current water quality conditions in the restored wetland. Reductions in nitrates might even have been dramatic had mean levels not been artificially inflated by non-point source run-off into the created freshwater marsh.

Perhaps, some of the most interesting results were those in which the trajectory of change differed completely between the two Study Areas. For example salinity decreased within natural marshes during the post-restoration sampling period, but increased considerably during this period in the Project Area: any climate-related reduction in salinities within these estuaries as a whole was obviously overwhelmed by the re-introduction of tidal waters to the artificially maintained freshwater environment of the former dairy ranch. Similarly, detection of total ammonia decreased in the restored wetland after levee breaching, but increased considerably in natural marshes. Factors driving this change are not understood, but similar increases have been observed at other sampling sites in the Tomales Bay during recent years (Rob Carson, TBWC, *pers. comm*.).

Ultimately, restoration of more than 600 acres of historic floodplain/marshplain is expected to not only restore water quality conditions within the Project Area, but Tomales Bay itself. Therefore, one of the most important indicators of the success of this project will be changes in concentrations and, even more importantly, loading between upstream and downstream sampling locations. As was expected, during the first four years after restoration, loading rates of pathogens and presumably nitrates actually increased in the Project Area relative to pre-restoration conditions, because, prior to levee removal, the pastures had either no direct connection to Lagunitas or other creeks (East Pasture) or only muted tidal connection (West Pasture) and, therefore, were only very infrequently in a position to contribute to downstream “loading.” It is likely that watershed-scale benefits will take time to be realized due to the continuing evolution occurring within the Project Area, as pasture vegetation continues to die off and convert into more natural salt- and brackish marsh vegetation communities.

Where Do Monitoring and Restoration Efforts Go From Here

Monitoring

Ultimately, monitoring of water quality and other hydrological variables will become part of a larger evaluation of the success fullness of restoration efforts. Based on evaluation of preliminary data, predicted restoration changes, and results from some of the progress criteria analyses proposed in the Long-Term Monitoring Program Framework: Part I (Parsons 2005), it appears that some water quality monitoring variables might be more capable of discerning change between pre-restoration and restored conditions and the direction of the evolutionary restoration trajectory (i.e., are restored wetlands becoming more like reference marshes?) than others. For example, the pattern of salinities between the Project Area and Reference Areas may never totally converge, because the Project Area receives more direct, abundant, and perennial freshwater inputs than Reference Areas. Some factors such as salinity may not seemingly not represent a good indicator for evaluating improvement in conditions within the Project Area and convergence of conditions with those observed in Reference Areas, but may ultimately be important as harbingers of potential future changes in the system from direct and indirect effects of climate change, including changes in pH, water level, extent of high tides, and salinity.

Photograph of restored marsh by Louis Jaffe

For the fifth year of Full Restoration, we will continue quarterly synoptic sampling of field parameters, nutrients, and pathogens, although the number of analytes will be reduced due to funding constraints. In keeping with the goals outlined in our analysis of Pre-Restoration data (Parsons 2009), we have improved our monitoring approach by increasing frequency and spatial coverage of sampling during storm events and better assessing nutrients such as total ammonia and total dissolved phosphates through use of analytical techniques with lower laboratory detection limits. While monitoring is focused on assessing change resulting from restoration, our results show that we will need to constantly take into account more system-wide or even global changes resulting from climatic variability, non-point source discharge issues, and climate change, which ultimately may have a significant effect on both Project Area and Reference Area systems.

Using Monitoring Information for Better Management and Restoration

One of the values of this monitoring program is that it enables the Seashore to pinpoint areas where remedial action and further future restoration might be necessary. Even after restoration, consistently high nitrates and, at times, fecal coliform levels have been detected flowing into the southern side of the newly created Tomasini Triangle Freshwater Marsh. Prior to restoration, approximately 7 percent of the samples exceeded 44 mg/L – NO3 equivalent to the 10 mg/L nitrate-N EPA standard for human consumption – and all of these exceedances came from this inflow sampling point. In addition, fecal coliform levels consistently exceeded 160,000 mpn/100ml. It was hoped that removal of agricultural management as part of restoration would improve conditions in this area, particularly as the marsh was constructed as habitat for federally threatened California red-legged frog. However, as discussed earlier in this report, while pollutant levels have dropped dramatically after restoration elsewhere in the Giacomini Ranch, they have remained high in this area, accounting for quite a few of the outlier points in graphs (Figure 9). This sampling site continues to show elevated nitrates even after restoration and exceeded 10 mg/L during every sampling event in Years 2, 3, and 4 and 75% of the events in Year 1.

Some of these waters being conveyed to the marsh appear to come from a ditch on the Point Reyes Mesa that funnels stormwater run-off during periods of heavy rainfall from the southwestern portion of the town into a swale that flows into the marsh. The Regional Water Quality Control Board had sampled this ditch in 2001 as part of the Tomales Bay Pathogen Study (RWQCB 2001) and found that fecal coliform levels were elevated during storm events, with levels ranging from 333 to 4,100 mpn/100 ml depending on the storm event and time of sampling during the event (RWQCB 2001).

While this stormwater run-off source accounts for some of the inflow into the Tomasini Triangle Marsh, site investigation has revealed that there are other sources of pollutants to the newly restored wetlands. A PVC pipe was found upslope of the Seashore’s sampling point that conveys a considerable amount of water to the marsh throughout the year. Sampling of this non-point source discharge over 6 months in Year 2 showed consistently high nitrate levels ranging around 30 mg/L, with concentrations occasionally as high as 53 mg/L (R. Carson, TBWC, unpub. data). The source of this discharge is not entirely certain, but, based on some planning documents that were reviewed, this pipe may have been installed originally in the 1980s to improve overall drainage of groundwater in the Point Reyes Mesa and, thereby, improve conditions for installation of septic systems associated with new residential development. Unfortunately, either current or past sources of pollutants are apparently being “captured” by this groundwater flow diversion and diverted into the newly restored wetland, thereby greatly elevating nutrients in this freshwater marsh created as special status species habitat.

Interestingly, fecal coliform levels in outflow from this pipe was typically low, and MBAS – the surfactant found in detergents – was only detected in trace amounts (R. Carson, TBWC, unpub. data). In contrast, fecal coliform levels at the sampling site on the marsh boundary during dry sampling events still continue to be high, although they have dropped to some degree after restoration. These results suggest that, even if the quality of stormwater run-off was improved, and the pipe outflow was eliminated, there would still continue to be inflow of pollutants into the marsh, probably due to the influence of nearby septic systems on the groundwater table.

While no one action may solve this issue, any management or restoration actions undertaken could reduce pollutant levels and improve quality of the Tomasini Triangle Marsh, which supports numerous birds, fish, and amphibians, some of which are federally listed species. In addition, reductions in nutrients may reduce spread or establishment of invasive non-native species that are now present in the marsh such as cattails (*Typha angustifolia*; *Typha Xglauca*) or even native floating emergent species that can establish monocultures in high nutrient conditions (*Hydrocotyle ranunculoides; Azolla fillucoides*).

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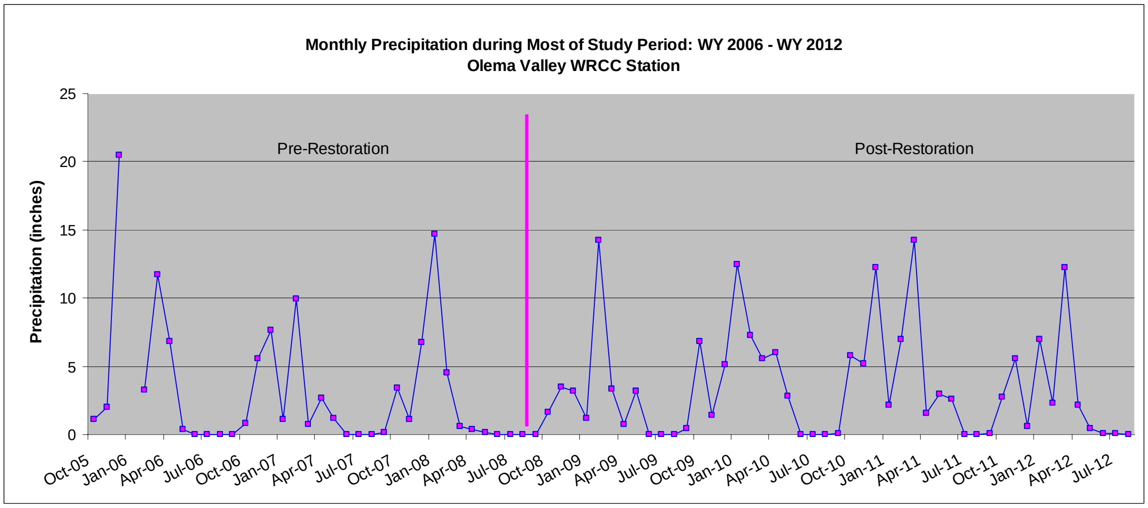


Figure 1. Monthly precipitation levels between WY 2006-WY 2012. Western Regional Data Climate Center: Olema Valley station. Note that sampling actually started in WY 2003, but data not available for this period. Data to left of line is pre-restoration; data to right of line is post-restoration.

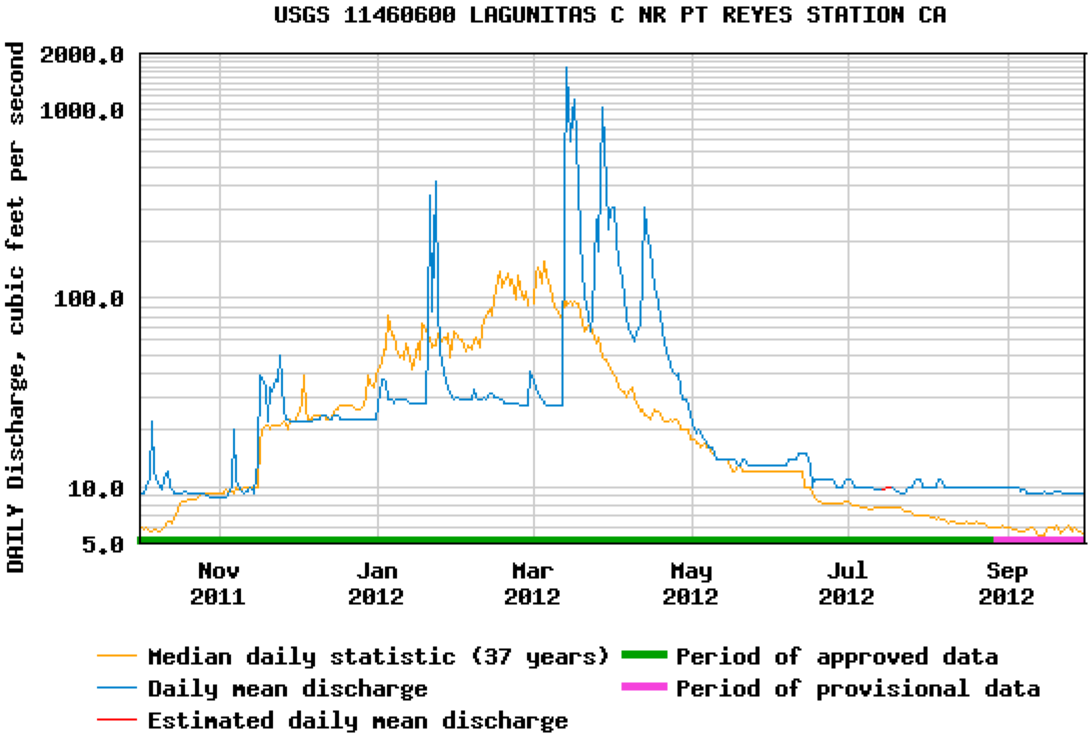
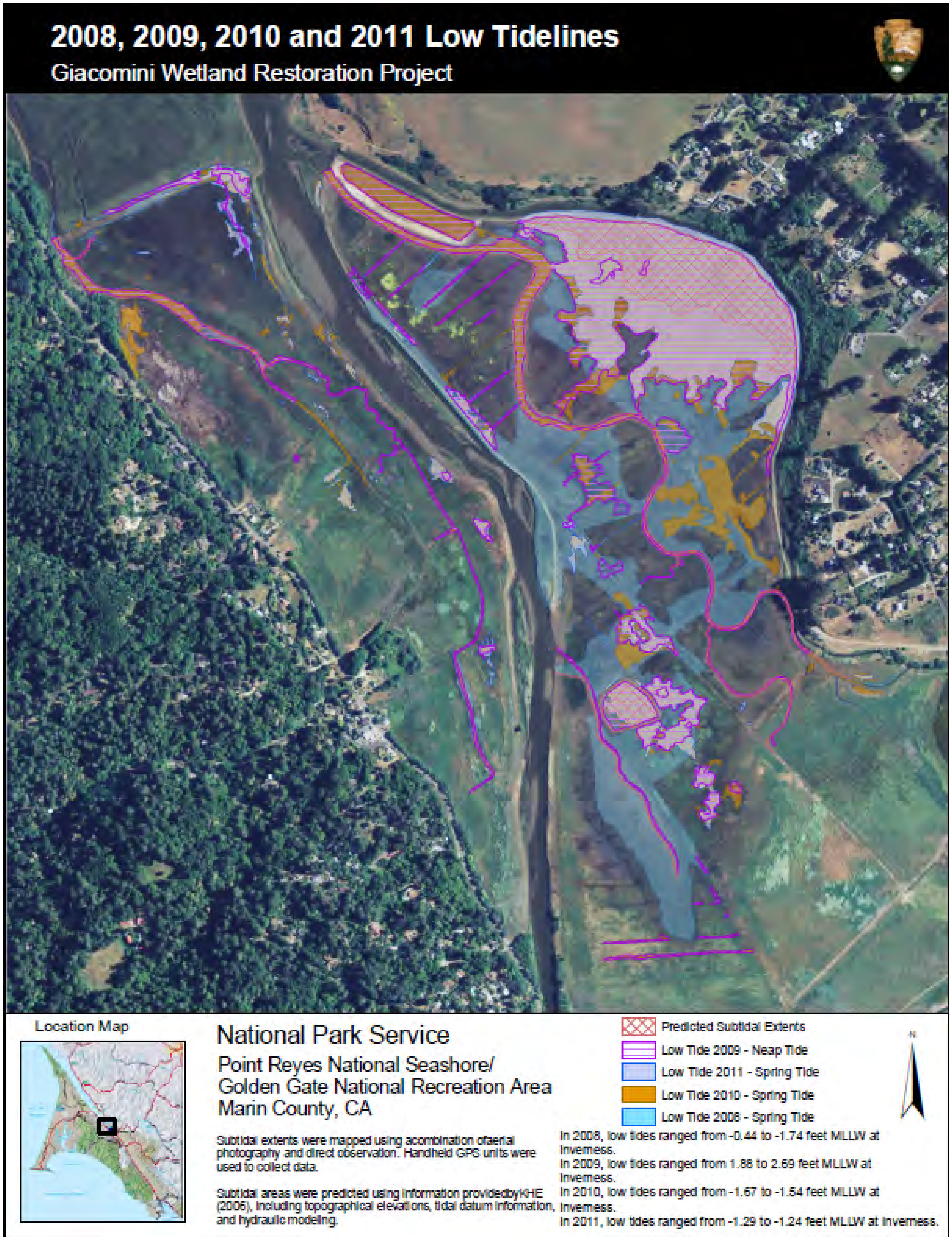


Figure 2. Lagunitas Creek discharge in Year 4 or WY 2012. Graph courtesy of USGS.



Subtidal extents were mapped using acombination ofaerial photography and direct observation. Handheld GPS units were used to collect data.

Subtidal areas were predicted using information providedbyKHE (2006), including topographical elevations, tidal datum information, and hydraulic modeling.

In 2008, low tides ranged from -0.44 to -1.74 feet MLLW at Inverness.
In 2009, low tides ranged from 1.88 to 2.69 feet MLLW at Inverness.
In 2010, low tides ranged from -1.67 to -1.54 feet MLLW at Inverness.
In 2011, low tides ranged from -1.29 to -1.24 feet MLLW at Inverness.

Figure 3. Low tidelines under spring and neap tide conditions since restoration was implemented. Colored areas represent inundated areas under extreme low tide conditions. Predicted refers to areas that were predicted by hydrologic modeling to remain subtidal or inundated under fully evolved marsh conditions.

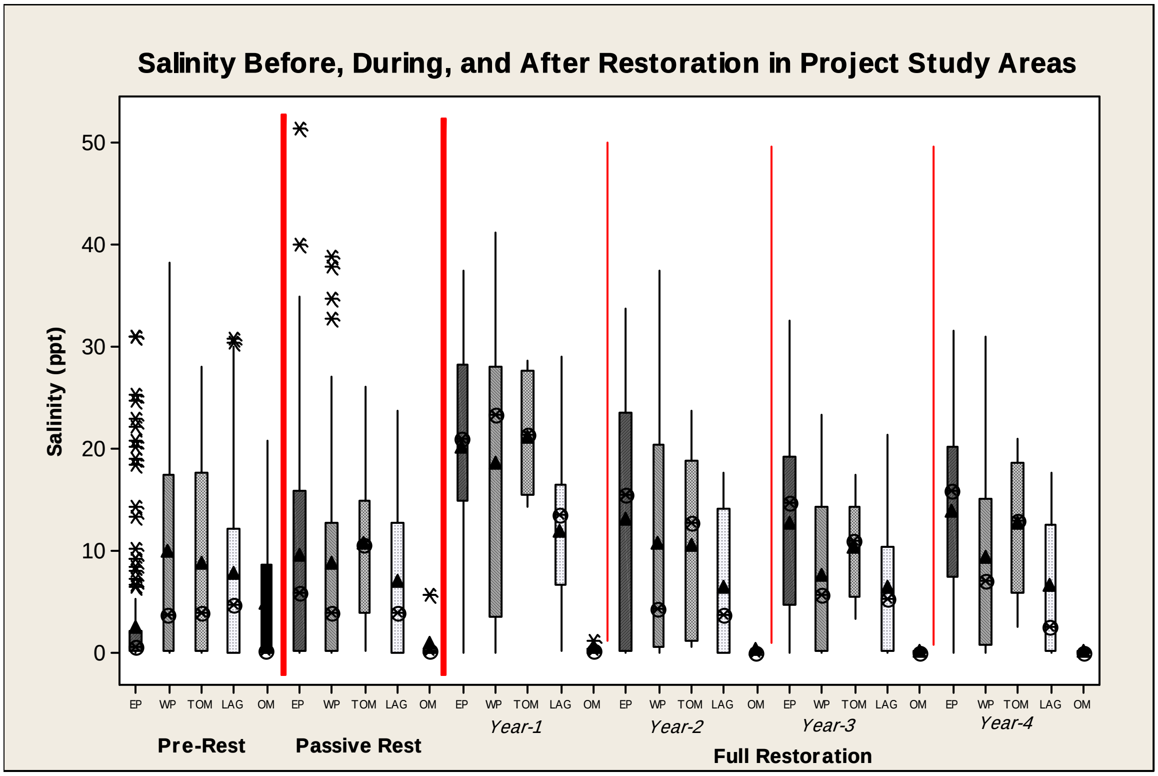


Figure 4. Average, median, and other summary statistics for salinity in the Project Area subsampling units Pre-Restoration, during Passive Restoration, and in the first four years of Full Restoration.

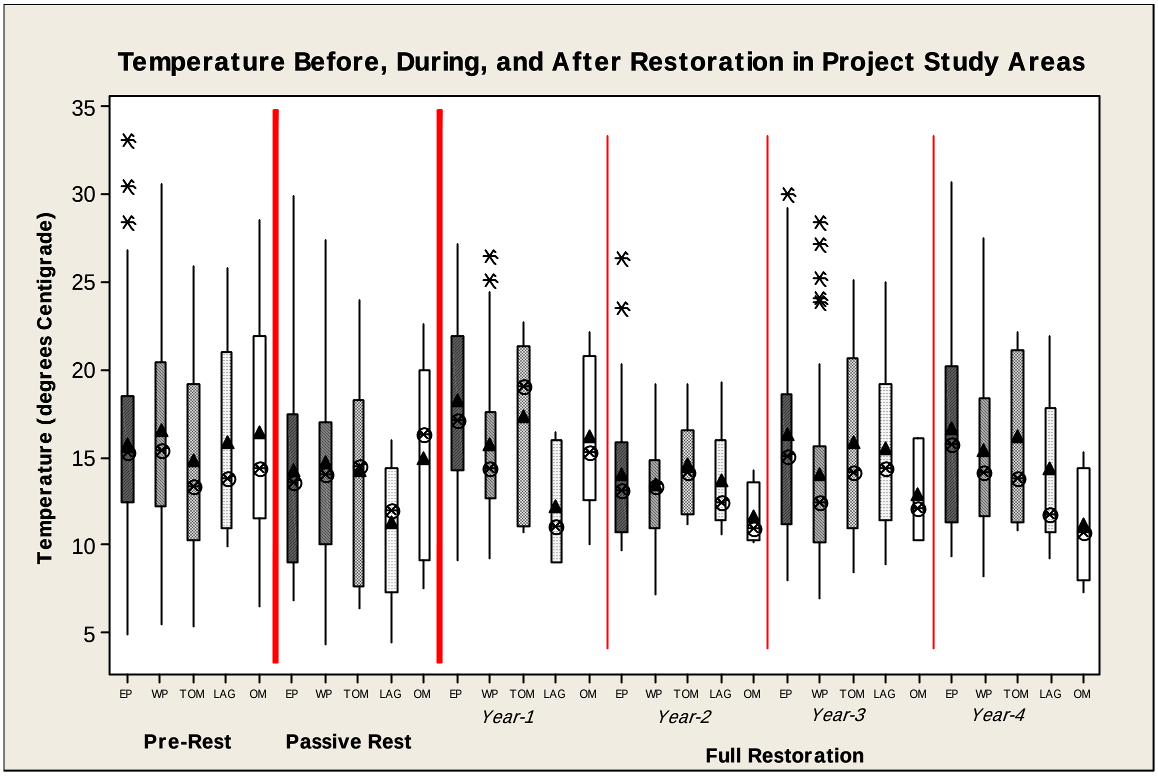


Figure 5. Average, median, and other summary statistics for temperature for Project Area subsampling units Pre-Restoration, during Passive Restoration, and in the first four years of Full Restoration.

Boxplots indicate first and third quartiles (25%, 75%). Lines indicate 10th and 90th percentiles. Medians are indicated by diagonal-hatched circle, with means designate by black triangles.

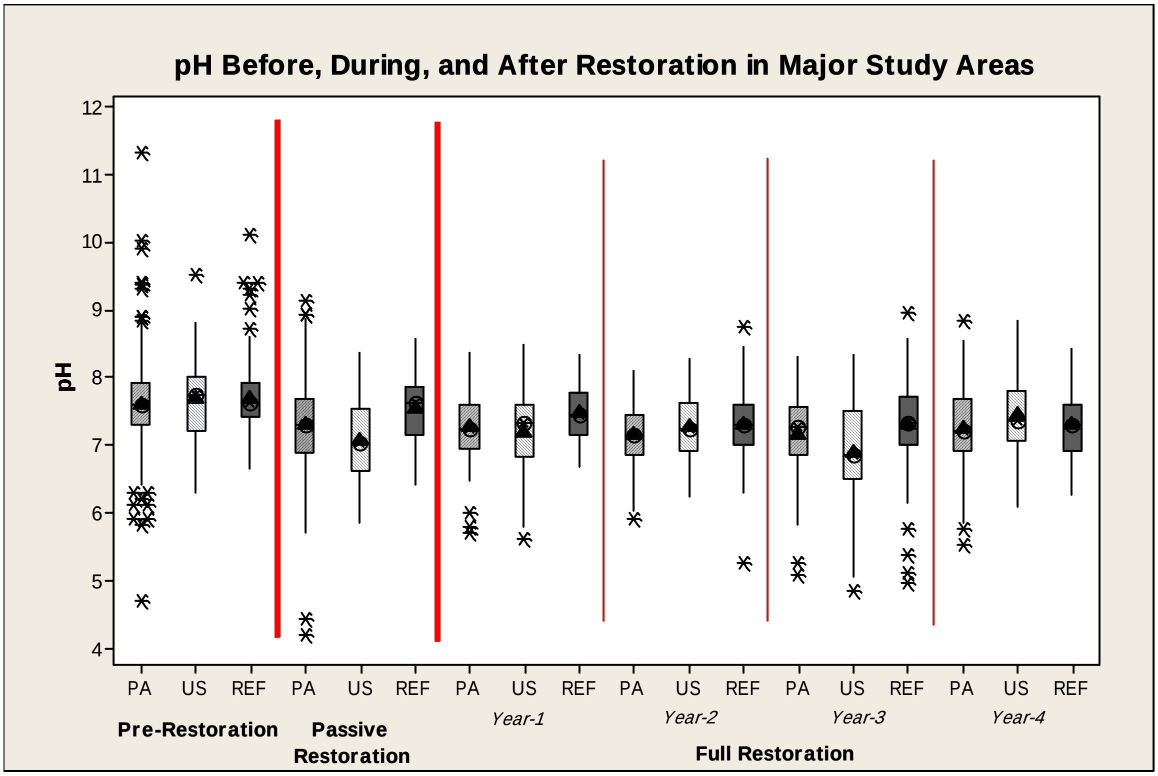


Figure 6. Average, median, and other summary statistics for pH for Study Areas Pre-Restoration, during Passive Restoration, and in the first four years of Full Restoration.

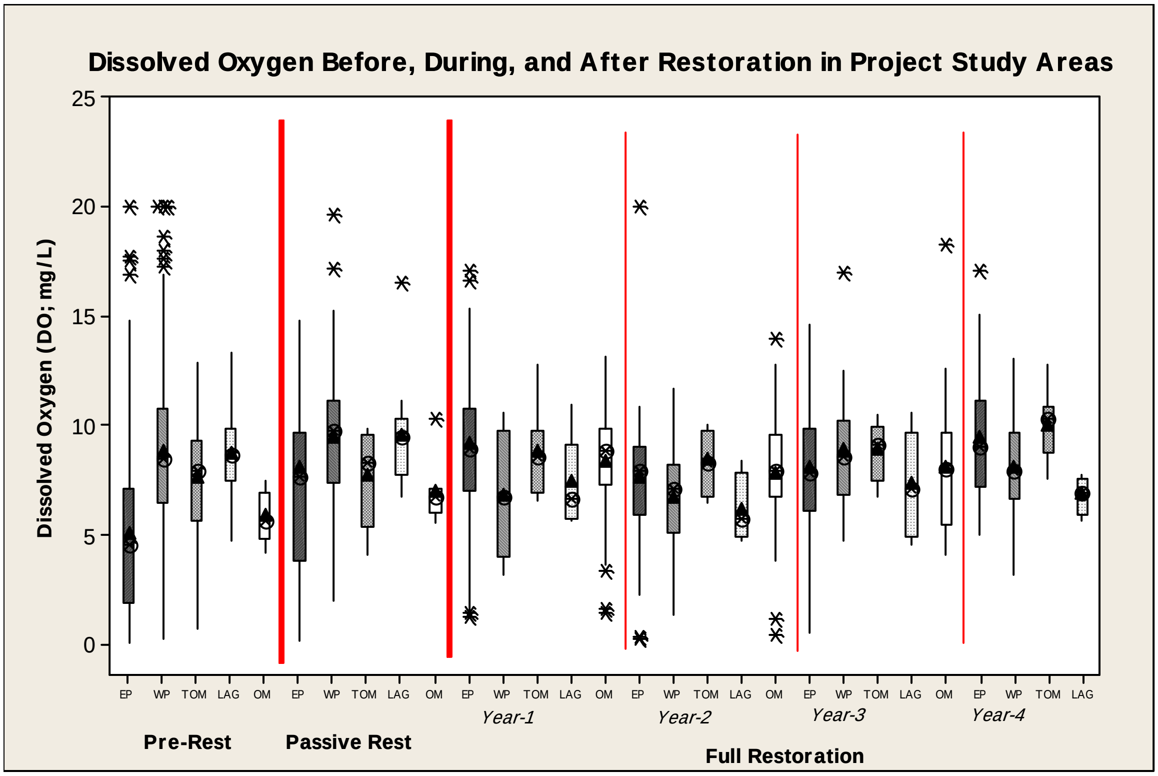


Figure 7. Average, median, and other summary statistics for dissolved oxygen for sub-sampling areas in the Project Area Pre-Restoration, during Passive Restoration, and in the first four years of Full Restoration.

Boxplots indicate first and third quartiles (25%, 75%). Lines indicate 10th and 90th percentiles. Medians are indicated by diagonal-hatched circle, with means designate by black triangles.

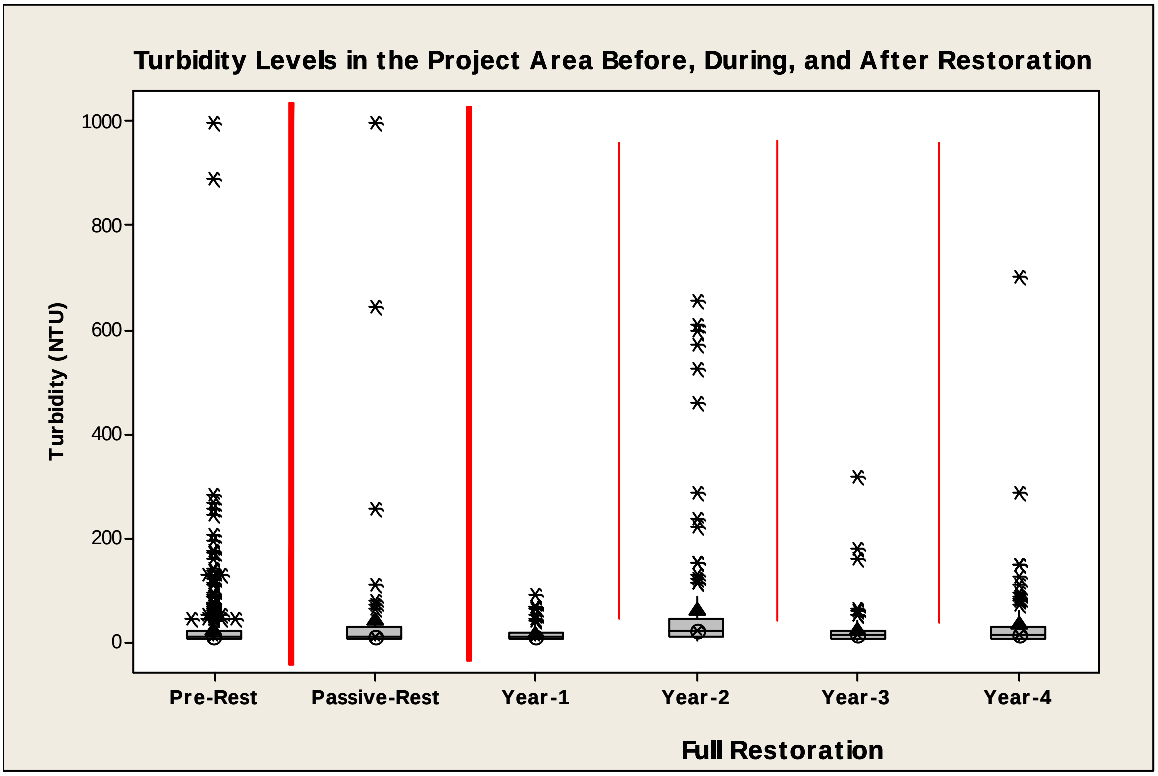


Figure 8. Average, median, and other summary statistics for turbidity in the Project Area Pre-Restoration, during Passive Restoration, and in the first four years of Full Restoration.

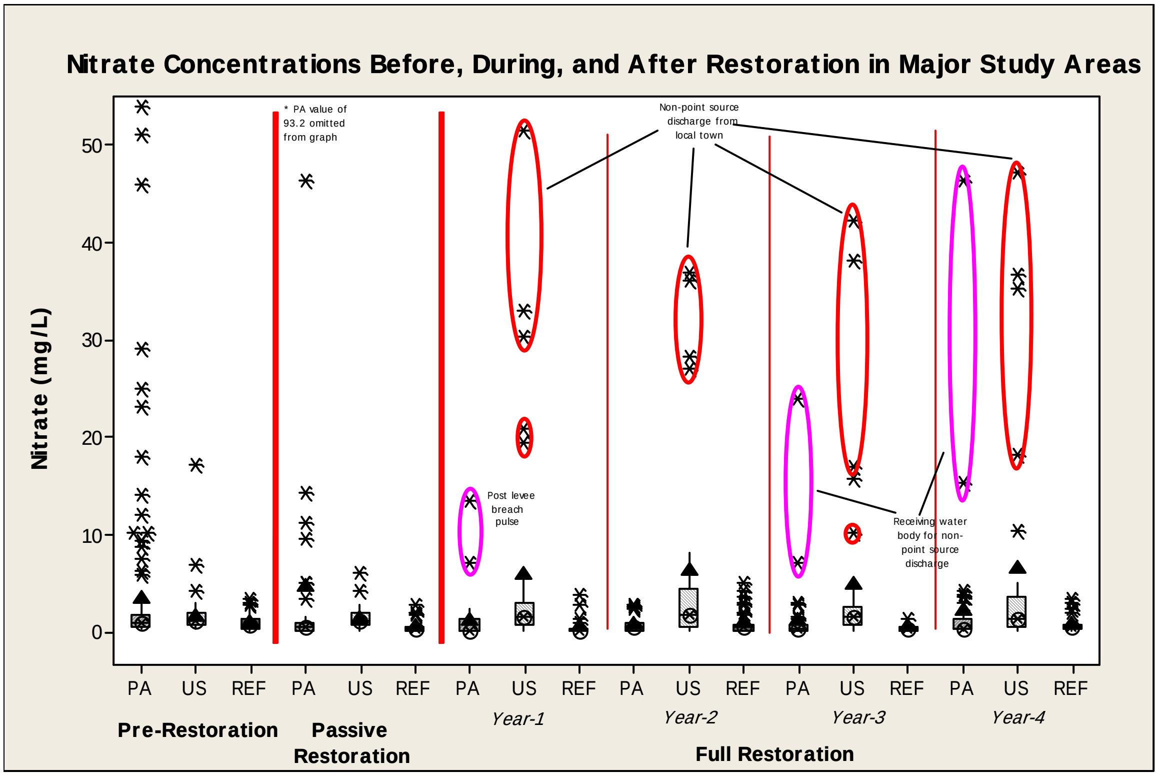


Figure 9. Average, median, and other summary statistics for nitrates (NO3-) for Study Areas Pre-Restoration, during Passive Restoration, and in the first four years of Full Restoration.

Light-shaded grey boxplots indicate first and third quartiles (25%, 75%). Lines indicate 10th and 90th percentiles. Medians are indicated by diagonal-hatched circle, with means designate by black triangles.

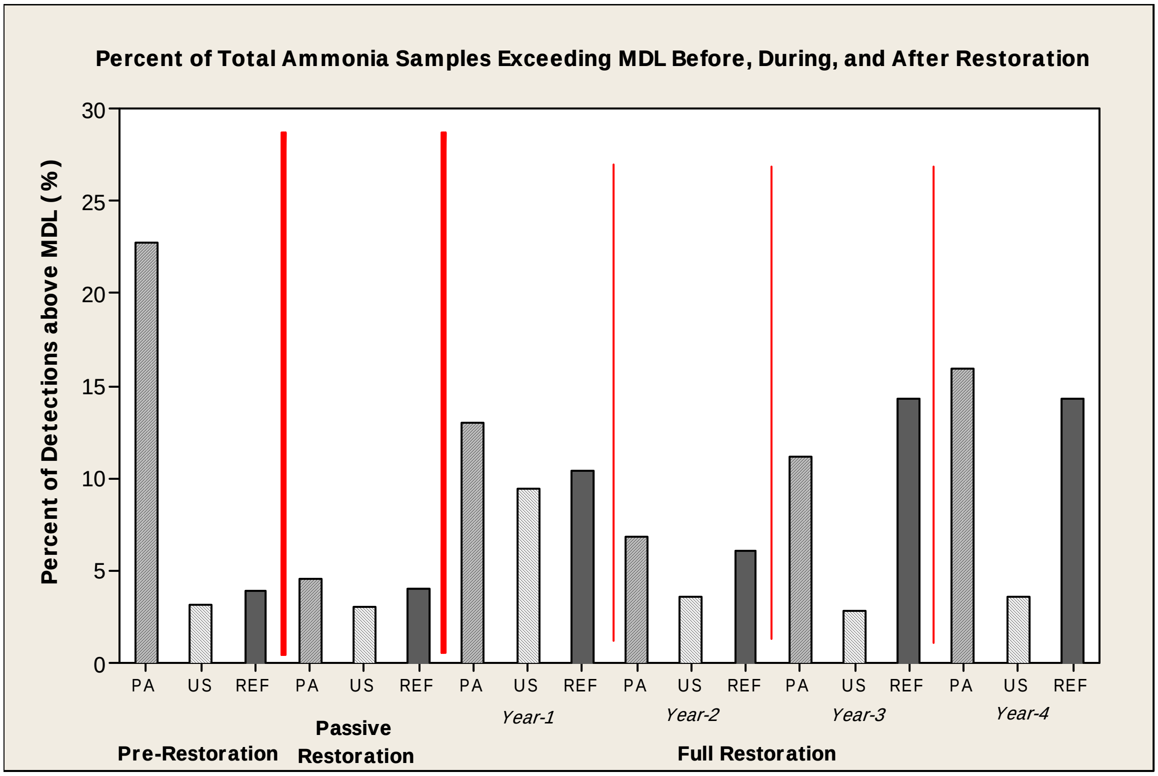


Figure 10. Percent of samples above Total Ammonia concentration detection limits for Study Areas Pre-Restoration, during Passive Restoration, and in the first four years of Full Restoration.

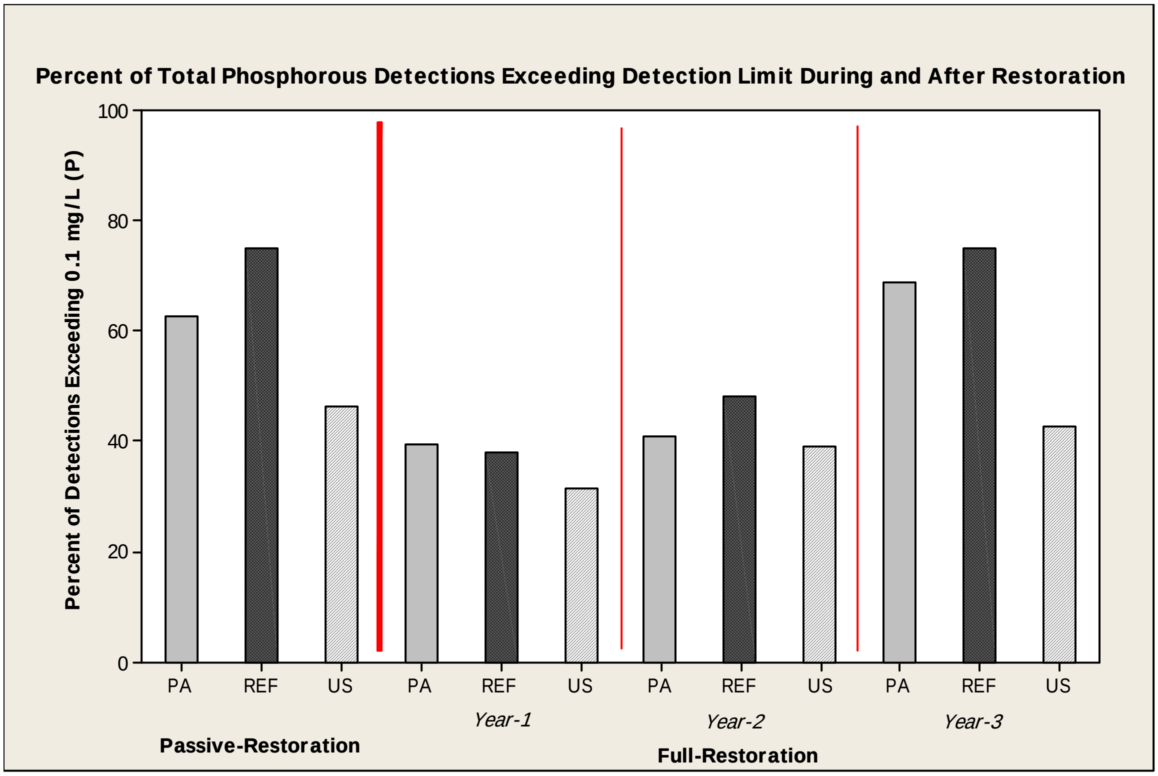


Figure 11. Percent of samples above Total Phosphorus concentration detection limits for Study Areas Pre-Restoration, during Passive Restoration, and in the first **three** years of Full Restoration. Full data set was not collected in Year 4.

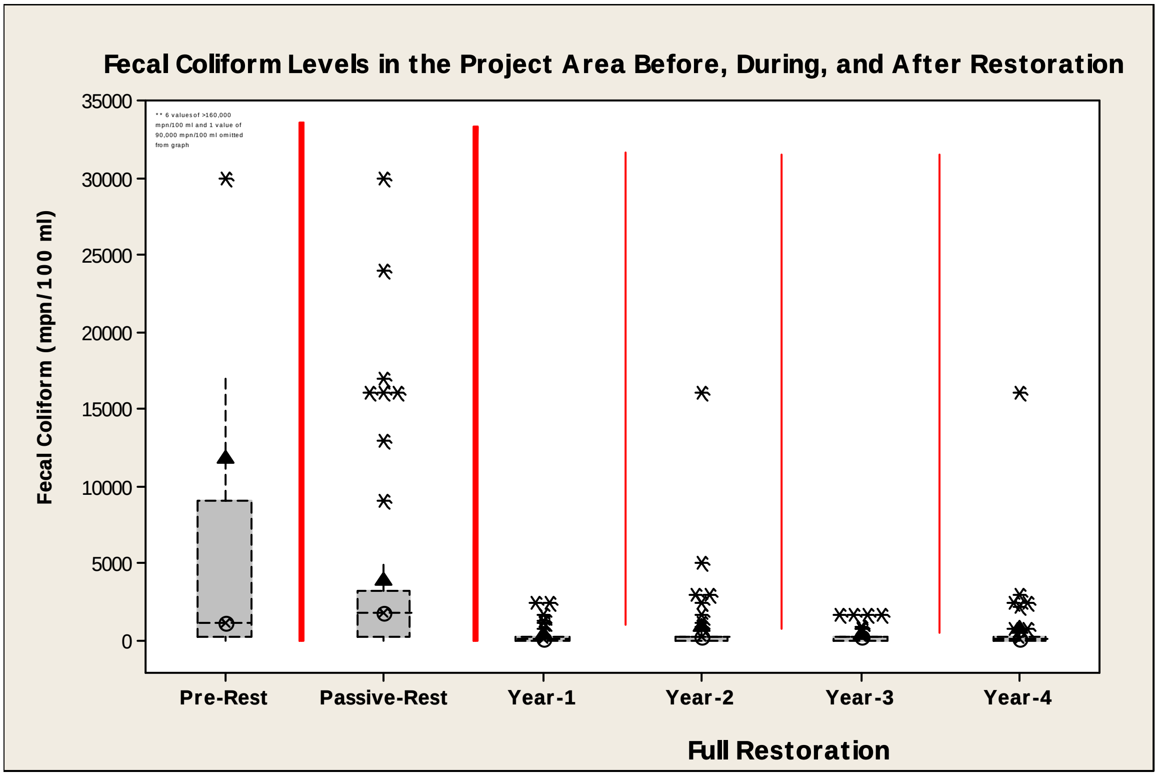


Figure 12. Average, median, and other summary statistics for fecal coliform concentrations for the Project Area Pre-Restoration, during Passive Restoration, and in the first four years of Full Restoration.

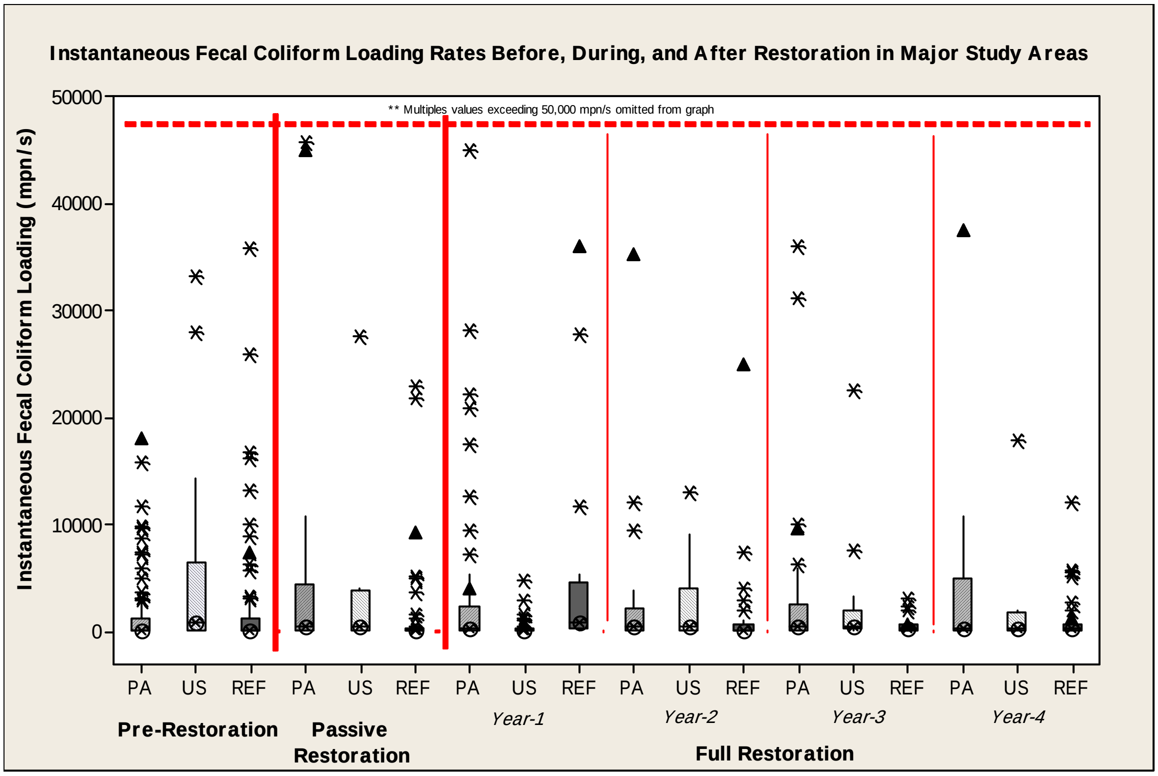


Figure 13. Average, median, and other summary statistics for fecal coliform loading for Study Areas Pre-Restoration, during Passive Restoration, and in the first three years of Full Restoration.

Light-shaded grey boxplots indicate first and third quartiles (25%, 75%). Lines indicate 10th and 90th percentiles. Medians are indicated by diagonal-hatched circle, with means designate by black triangles. Note: dashed lines for boxplots indicates both right- and left-censored data.

TBWC Final Technical Water Quality Report

Appendix B:

Water Quality Sampling Sites

TBWC Trends Program Sampling Stations

Tomales Bay Watershed CouncilSorted by ID

	Station ID	Station Name	Station Type	Latitude	Longitude
1	FV1	First Valley Creek upstream of SFD (38.09729°)	River/Stream (122.85241°)	38°5'50.244" North	122°51'8.676" West
2	KYS1	Keyes Creek at Hwy. 1 Bridge (38.2411°)	River/Stream (122.9052°)	38°14'27.96" North	122°54'18.72" West
3	LAG1	Lagunitas Creek at Green Bridge (Hwy 1) (38.0645°)	River/Stream (122.8056°)	38°3'52.2" North	122°48'20.1599" West
4	LAG6	Lagunitas Creek - Wetland-Bay Interface (38.084609°)	River/Stream (122.829063°)	38°5'4.590684" North	122°49'44.62503" West
5	LAGSPT	Lagunitas Creek in Samuel P Taylor at the USGS streamgage	River/Stream (38.02698°)	38°1'37.128" North (122.73641°)	122°44'11.0761" West
6	MC1	Millerton Creek upstream of tidal influence (38.11216°)	River/Stream (122.835°)	38°6'43.776" North	122°50'5.9999" West
7	MC1A	Millerton Creek River/Stream (38.10929°)	38°6'33.444" North (122.83977°)	122°50'23.172" West	
8	MP36.17	Tributary at MP 36.17, near Marconi (38.14012°)	River/Stream (122.87154°)	38°8'24.432" North	122°52'17.544" West
9	OLM11	Olema Creek at Bear Valley Road bridge - NPS gage site	River/Stream (38.04165°)	38°2'29.94" North (122.78957°)	122°47'22.4519" West
10	SG1	San Geronimo Creek at MMWD Gage (38.00955°)	River/Stream (122.701°)	38°0'34.38" North	122°42'3.6001" West
11	TB11	Tomales Bay - Inner Bay Site (38.10695°)	Ocean: Pacific Ocean (122.853164°)	38°6'25.02" North	122°51'11.3901" West
12	TB2	Tomales Bay - Outer Bay Site (38.206106°)	Ocean: Pacific Ocean (122.936967°)	38°12'21.98" North	122°56'13.0801" West
13	TB4	Tomales Bay - mid bay site (38.172725°)	Ocean: Pacific Ocean (122.906222°)	38°10'21.81" North	122°54'22.4" West
14	WG1	White Gulch just upstream of Bay input (38.19501°)	River/Stream (122.95138°)	38°11'42.036" North	122°57'4.9681" West
15	WKR1	Walker Creek at Hwy. 1 Bridge (38.23254°)	River/Stream (122.91295°)	38°13'57.144" North	122°54'46.62" West

TBWC Trends Program Sampling Stations cont...

Tomales Bay Watershed Council ***Sorted by ID***

	Station ID	Station Name	Station Type	Latitude	Longitude
16	WKR2	Walker Creek at Walker Creek Ranch (USGS gage site)	River/Stream (38.17511°)	38°10'30.396" North (122.81768°)	122°49'3.6479" West

Number of Stations for Tomales Bay Watershed Council: ***16***

Stations filtered for:
Organization = TBWC: Tomales Bay Watershed Council
Project = TRENDS: Long-Term Water-Quality Trends in Tomales Bay & Tributaries
Station = FV1: First Valley Creek upstream of SFD
KYS1: Keyes Creek at Hwy. 1 Bridge
LAG1: Lagunitas Creek at Green Bridge (Hwy 1)
LAG6: Lagunitas Creek - Wetland-Bay Interface
LAGSPT: Lagunitas Creek in Samuel P Taylor at the USGS streamgage
MC1: Millerton Creek upstream of tidal influence
MC1A: Millerton Creek
MP36.17: Tributary at MP 36.17, near Marconi
OLM11: Olema Creek at Bear Valley Road bridge - NPS gage site
SG1: San Geronimo Creek at MMWD Gage
TB11: Tomales Bay - Inner Bay Site
TB2: Tomales Bay - Outer Bay Site
TB4: Tomales Bay - mid bay site
WG1: White Gulch just upstream of Bay input
WKR1: Walker Creek at Hwy. 1 Bridge
WKR2: Walker Creek at Walker Creek Ranch (USGS gage site)

TBWC Source Area Program Sampling Stations

Tomales Bay Watershed Council ***Sorted by ID***

	Station ID	Station Name	Station Type	Latitude	Longitude	Elev.	County	Stat
1	CDM1	Camino Del Mar culvert outfall south of SFD	Channelized stream	38°6'33.75" North (38.109375°)	122°52'7.87" West (122.868853°)		MARIN	CA
2	CR1	Chicken Ranch Beach/Third Valley Creek downstream	River/Stream	38°6'34.57" North (38.109603°)	122°51'53.98" West (122.864994°)		MARIN	CA
3	CR2	Third Valley Creek upstream of beach	River/Stream	38°6'36.25" North (38.110069°)	122°52'4.93" West (122.868036°)		MARIN	CA
4	CR2C	Culvert from SFD to Third Valley Creek	Storm sewer	38°6'33.84" North (38.1094°)	122°51'56.68" West (122.865744°)		MARIN	CA
5	CR4	Third Valley Creek upstream of SFD culvert	River/Stream	38°6'33.83" North (38.109397°)	122°52'7.4" West (122.868722°)		MARIN	CA
6	CR5	Third Valley Creek upstream of Miwok Way	River/Stream	38°6'30.9" North (38.108583°)	122°52'14.1399" West (122.870594°)		MARIN	CA
7	CR5a	Downstream 3rd Valley Creek Tributary from SFD to the North	Land runoff	38°6'28.91" North (38.108031°)	122°52'18.94" West (122.871928°)		MARIN	CA
8	CR5b	Upstream 3rd Valley Creek Tributary from SFD to the North	Land runoff	38°6'31.29" North (38.108692°)	122°52'19.88" West (122.872189°)		MARIN	CA
9	CR6	Third Valley Creek upstream of Inverness Valley Inn	River/Stream	38°6'27.68" North (38.107689°)	122°52'22.25" West (122.872847°)		MARIN	CA
10	CRB	Chicken Ranch Beach, ditch B just outside fence marking Stat	River/Stream	38°6'36.23" North (38.110064°)	122°51'55.92" West (122.865533°)		MARIN	CA
11	CRB2	Upstream end of ditch B, sample upstream inflow to Keller's	River/Stream	38°6'36.25" North (38.110069°)	122°52'4.9299" West (122.868036°)		MARIN	CA
12	CRBEACH1	Chicken Ranch Beach 1	Ocean: Pacific Ocean	38°6'35.28" North (38.1098°)	122°51'52.776" West (122.86466°)		MARIN	CA

13	HD1	Heart's Desire Freshwater Outfall on Beach	River/Stream	38°7'57" North (38.1325°)	122°53'37.3201" West (122.8937°)	MARIN	CA
14	HD2.2A	Heart's Desire ditch on main Rd. just up from beach road		38°7'52.27" North (38.131186°)	122°53'40.47" West (122.894575°)	MARIN	CA
15	HD2A	Channel A upstream of Rd Xing	River/Stream	38°7'52.68" North (38.1313°)	122°53'39.8401" West (122.8944°)	MARIN	CA
16	HD2B	HD Channel B at base of hill	Land runoff	38°7'53.76" North (38.1316°)	122°53'33.72" West (122.8927°)	MARIN	CA
17	HD3A	HD Channel A upstream of upper road crossing	River/Stream	38°7'49.8" North (38.1305°)	122°53'42.5" West (122.895139°)	MARIN	CA
18	HD3B	Heart's Desire -southeast ditch flows W.	Land runoff	38°7'55.25" North (38.132014°)	122°53'35.43" West (122.893175°)	MARIN	CA
19	HD4B	Heart's Desire, ditch on southwest side into channel B	Land runoff	38°7'55.38" North (38.13205°)	122°53'36.11" West (122.893364°)	MARIN	CA
20	HDA	Main HD stream, just upstream of confluence with HDB	River/Stream	38°7'55.92" North (38.1322°)	122°53'38.0399" West (122.8939°)	MARIN	CA
21	HDB	South Fork of Heart's Desire Stream	Land runoff	38°7'55.2" North (38.132°)	122°53'37.3201" West (122.8937°)		
22	KYS1	Keyes Creek at Hwy. 1 Bridge	River/Stream	38°14'27.96" North (38.2411°)	122°54'18.72" West (122.9052°)	MARIN	CA
23	KYS2	Keyes Creek on petaluma-tomales rd. upstream of Hwy 1	River/Stream	38°14'31.71" North (38.242142°)	122°54'11.19" West (122.903108°)	MARIN	CA
24	KYS3	Keyes Creek on Irwin road	River/Stream	38°14'36.45" North (38.243458°)	122°53'50.71" West (122.897419°)	MARIN	CA
25	KYS3b	Keyes Creek Tributary on Irwin Rd.	River/Stream	38°14'42.36" North (38.2451°)	122°53'50.5" West (122.897361°)	MARIN	CA
26	KYS3B_UP	Upstream of KYS3b	River/Stream	38°14'53.988" North (38.24833°)	122°53'45.3479" West (122.89593°)	MARIN	CA
27	KYS4	Keys Creek upstream at MP3.66	River/Stream	38°14'44.62" North	122°52'20.37" West	MARIN	CA

				(38.245728°)	(122.872325°)			
28	LAG1	Lagunitas Creek at Green Bridge (Hwy 1)	River/Stream	38°3'52.2" North (38.0645°)	122°48'20.1599" West (122.8056°)		MARIN	CA
29	LAGSPT	Lagunitas Creek in Samuel P Taylor at the USGS streamgage	River/Stream	38°1'37.128" North (38.02698°)	122°44'11.0761" West (122.73641°)		MARIN	CA
30	MC1	Millerton Creek upstream of tidal influence	River/Stream	38°6'43.776" North (38.11216°)	122°50'5.9999" West (122.835°)		MARIN	CA
31	OLM11	Olema Creek at Bear Valley Road bridge - NPS gage site	River/Stream	38°2'29.94" North (38.04165°)	122°47'22.4519" West (122.78957°)		MARIN	CA
32	Park St	Woodacre Creek mainstem	River/Stream	38°0'41.5562" North (38.011543°)	122°38'41.5572" West (122.644877°)		MARIN	CA
33	SG1	San Geronimo Creek at MMWD Gage	River/Stream	38°0'34.38" North (38.00955°)	122°42'3.6001" West (122.701°)	208 ft	MARIN	CA
34	TOM1	Tomasini Creek at Mesa Road	River/Stream	38°4'15.53" North (38.070981°)	122°48'36.3599" West (122.8101°)		MARIN	CA
35	TOM2	Tomasini Creek off of Viento Rd.	River/Stream	38°4'27.43" North (38.074286°)	122°48'32.94" West (122.80915°)		MARIN	CA
36	TOM4	Tomasini Creek just downstream of Highway 1 culvert	River/Stream	38°4'47.34" North (38.079817°)	122°48'21.37" West (122.805936°)		MARIN	CA
37	TOM5	Tomasini Creek just downstream of landfill cattle guard	River/Stream	38°4'59.01" North (38.083058°)	122°48'16.2298" West (122.804508°)		MARIN	CA
38	TOM6	Tomasini Creek tributary 200m upstream of Hwy. 1	River/Stream	38°5'1.87" North (38.083853°)	122°48'21.1601" West (122.805878°)		MARIN	CA
39	TOMPIPE	Mystery Pipe	Spring	38°4'9.5057" North (38.069307°)	122°48'37.4579" West (122.810405°)		MARIN	CA
40	TP1	Turtle Pond at Chicken Ranch Beach on SE corner	River/Stream	38°6'36.35" North (38.110097°)	122°51'56.5599" West (122.865711°)		MARIN	CA
41	WKR1	Walker Creek at Hwy. 1 Bridge	River/Stream	38°13'57.144" North	122°54'46.62" West		MARIN	CA

				(38.23254°)	(122.91295°)		
42	WKR2	Walker Creek at Walker Creek Ranch (USGS gage site)	River/Stream	38°10'30.396" North (38.17511°)	122°49'3.6479" West (122.81768°)	MARIN	CA
43	WS17	East Fork Woodacre Creek	River/Stream	38°0'23.2293" North (38.006453°)	122°38'14.3353" West (122.637315°)	MARIN	CA
44	WS18	West Fork Woodacre Creek	River/Stream	38°0'19.4722" North (38.005409°)	122°38'16.5276" West (122.637924°)	MARIN	CA
45	WS19	Woodacre Creek	River/Stream	38°0'46.177" North (38.012827°)	122°38'49.0402" West (122.646956°)	MARIN	CA
46	WS20	San Geronimo Creek at Roy's Pools	River/Stream	38°0'45.864" North (38.01274°)	122°39'46.7029" West (122.662973°)	MARIN	CA
47	WS21	Montezuma Creek	River/Stream	38°0'50.4381" North (38.014011°)	122°41'22.3196" West (122.689533°)	MARIN	CA
48	WS22	Arroyo Creek	River/Stream	38°0'53.0501" North (38.014736°)	122°41'40.9277" West (122.694702°)	MARIN	CA
49	WS23	San Geronimo Creek at Inkwells	River/Stream	38°0'17.4202" North (38.004839°)	122°42'30.529" West (122.70848°)	MARIN	CA

Number of Stations for Tomales Bay Watershed Council: 49

Stations filtered for:
Organization = TBWC: Tomales Bay Watershed Council
Project = SAP50II: Source Area Monitoring in Tomales Bay Watershed (Prop 50 II)
With Visit Date (>=10/1/2007 and <=9/30/2012)

NPS Giacomini Wetlands Monitoring Program Sampling Stations

Tomales Bay Watershed Council *Sorted by ID*

	Station ID	Station Name	Station Type	Latitude	Longitude	Elev.	County	Stat
1	EPOS3/Pond		Wetland: Undifferentiated	38°4'44.0328" North (38.078898°)	122°49'21.7763" West (122.822716°)		MARIN	CA
2	EPPanne		Wetland: Undifferentiated	38°4'40.5498" North (38.07793°)	122°49'2.1126" West (122.817253°)		MARIN	CA
3	EUC1		Wetland: Undifferentiated	38°4'8.4559" North (38.069016°)	122°48'38.4123" West (122.81067°)		MARIN	CA
4	FIS1		Wetland: Undifferentiated	38°4'14.0477" North (38.070569°)	122°49'31.4905" West (122.825414°)		MARIN	CA
5	FIS2		Wetland: Undifferentiated	38°4'30.5896" North (38.075164°)	122°49'33.6186" West (122.826005°)		MARIN	CA
6	FIS3		Wetland: Undifferentiated	38°4'34.5257" North (38.076257°)	122°49'38.3196" West (122.827311°)		MARIN	CA
7	FIS4		Wetland: Undifferentiated	38°4'39.3517" North (38.077598°)	122°49'47.7878" West (122.829941°)		MARIN	CA
8	FIS4.5		Wetland: Undifferentiated	38°4'39.5412" North (38.07765°)	122°49'50.9129" West (122.830809°)		MARIN	CA
9	FIS5		Wetland: Undifferentiated	38°4'42.6675" North (38.078519°)	122°49'56.1257" West (122.832257°)		MARIN	CA
10	FIS7		Wetland: Undifferentiated	38°4'48.0207" North (38.080006°)	122°49'56.8259" West (122.832452°)		MARIN	CA
11	FIS8		Wetland: Undifferentiated	38°4'59.8537" North (38.083293°)	122°50'5.8521" West (122.834959°)		MARIN	CA
12	FIS8 Creek		Wetland: Undifferentiated	38°4'58.3324" North (38.08287°)	122°50'11.2438" West (122.836457°)		MARIN	CA

13	LAG1	Lagunitas Creek at Green Bridge (Hwy 1)	River/Stream	38°3'52.2" North (38.0645°)	122°48'20.1599" West (122.8056°)	MARIN	CA
14	LAG2_GWRP		Wetland: Undifferentiated	38°3'47.4561" North (38.063182°)	122°48'45.8746" West (122.812743°)	MARIN	CA
15	LAG3		Wetland: Undifferentiated	38°3'46.2731" North (38.062854°)	122°49'10.3439" West (122.81954°)	MARIN	CA
16	LAG3.5		Wetland: Undifferentiated	38°4'17.6729" North (38.071576°)	122°49'14.656" West (122.820738°)	MARIN	CA
17	LAG4		Wetland: Undifferentiated	38°4'26.4147" North (38.074004°)	122°49'16.2193" West (122.821172°)	MARIN	CA
18	LAG5		Wetland: Undifferentiated	38°4'46.773" North (38.079659°)	122°49'38.5771" West (122.827383°)	MARIN	CA
19	LAG6	Lagunitas Creek - Wetland-Bay Interface	River/Stream	38°5'4.590684" North (38.084609°)	122°49'44.62503" West (122.829063°)	MARIN	CA
20	LAGSIDE1		Wetland: Undifferentiated	38°4'5.8266" North (38.068285°)	122°49'6.9367" West (122.818594°)	MARIN	CA
21	LAGSIDE2		Wetland: Undifferentiated	38°4'14.0461" North (38.070568°)	122°49'12.025" West (122.820007°)	MARIN	CA
22	LIM1		Wetland: Undifferentiated	38°1'51.8939" North (38.031082°)	122°53'4.2304" West (122.884508°)	MARIN	CA
23	LIM2		Wetland: Undifferentiated	38°1'48.3258" North (38.03009°)	122°53'13.6778" West (122.887133°)	MARIN	CA
24	LIM3		Wetland: Undifferentiated	38°1'45.4338" North (38.029287°)	122°53'8.446" West (122.885679°)	MARIN	CA
25	LIM5/Pond		Wetland: Undifferentiated	38°1'44.2944" North (38.028971°)	122°53'4.0752" West (122.884465°)	MARIN	CA
26	LUCC1		Wetland: Undifferentiated	38°4'24.7892" North (38.073553°)	122°49'38.4744" West (122.827354°)	MARIN	CA

27	LUCC2		Wetland: Undifferentiated	38°4'26.5013" North (38.074028°)	122°49'40.0154" West (122.827782°)	MARIN	CA
28	New Duck Pond		Wetland: Undifferentiated	38°4'13.4128" North (38.070392°)	122°49'8.2796" West (122.818967°)	MARIN	CA
29	OLDTOM1.5		Wetland: Undifferentiated	38°4'15.2294" North (38.070897°)	122°48'47.3994" West (122.813166°)	MARIN	CA
30	OLDTOM2		Wetland: Undifferentiated	38°4'15.3579" North (38.070933°)	122°48'51.3052" West (122.814251°)	MARIN	CA
31	OLDTOM3		Wetland: Undifferentiated	38°4'42.0633" North (38.078351°)	122°48'57.987" West (122.816108°)	MARIN	CA
32	OLDTOM4		Wetland: Undifferentiated	38°4'44.4962" North (38.079027°)	122°49'21.4085" West (122.822613°)	MARIN	CA
33	OM1		Wetland: Undifferentiated	38°3'28.8834" North (38.058023°)	122°48'35.221" West (122.809784°)	MARIN	CA
34	OM2		Wetland: Undifferentiated	38°3'46.2188" North (38.062839°)	122°48'45.78" West (122.812717°)	MARIN	CA
35	TOM1	Tomasini Creek at Mesa Road	River/Stream	38°4'15.53" North (38.070981°)	122°48'36.3599" West (122.8101°)	MARIN	CA
36	TOMPOND		Wetland: Undifferentiated	38°4'11.4105" North (38.069836°)	122°48'38.3112" West (122.810642°)	MARIN	CA
37	TOMSIDE1		Wetland: Undifferentiated	38°4'14.9509" North (38.07082°)	122°49'1.2321" West (122.817009°)	MARIN	CA
38	TOMSIDE2		Wetland: Undifferentiated	38°4'20.9948" North (38.072499°)	122°49'3.4515" West (122.817625°)	MARIN	CA
39	TOMSL1		Wetland: Undifferentiated	38°4'14.9343" North (38.070815°)	122°48'52.3576" West (122.814544°)	MARIN	CA
40	TOMSL2		Wetland: Undifferentiated	38°4'30.2936" North (38.075082°)	122°49'12.0037" West (122.820001°)	MARIN	CA
41	TOMSL3		Wetland: Undifferentiated	38°4'42.9702" North (38.078603°)	122°49'27.1351" West (122.824204°)	MARIN	CA

42	TOMSL4	Wetland: Undifferentiated	38°4'45.9822" North (38.07944°)	122°49'32.3412" West (122.82565°)	MARIN	CA
43	UM1	Wetland: Undifferentiated	38°4'45.7423" North (38.079373°)	122°49'54.2045" West (122.831723°)	MARIN	CA
44	UM2	Wetland: Undifferentiated	38°4'52.8161" North (38.081338°)	122°49'45.8398" West (122.8294°)	MARIN	CA
45	UM3	Wetland: Undifferentiated	38°4'55.9438" North (38.082207°)	122°49'51.2057" West (122.83089°)	MARIN	CA
46	UM4	Wetland: Undifferentiated	38°5'1.7998" North (38.083833°)	122°49'52.1974" West (122.831166°)	MARIN	CA
47	UM5	Wetland: Undifferentiated	38°4'58.4384" North (38.0829°)	122°50'2.1435" West (122.833929°)	MARIN	CA
48	UMPond	Wetland: Undifferentiated	38°4'51.6236" North (38.081007°)	122°49'46.2142" West (122.829504°)	MARIN	CA
49	WCM1	Wetland: Undifferentiated	38°13'0.5157" North (38.21681°)	122°55'31.7752" West (122.925493°)	MARIN	CA
50	WCM2	Wetland: Undifferentiated	38°12'59.134" North (38.216426°)	122°55'34.8086" West (122.926336°)	MARIN	CA
51	WCM3	Wetland: Undifferentiated	38°12'47.0385" North (38.213066°)	122°55'43.6487" West (122.928791°)	MARIN	CA
52	WCM5	Wetland: Undifferentiated	38°12'51.792" North (38.214387°)	122°55'32.0815" West (122.925578°)	MARIN	CA
53	WCM6	Wetland: Undifferentiated	38°12'47.5708" North (38.213214°)	122°55'32.2046" West (122.925612°)	MARIN	CA
54	WPCulv	Wetland: Undifferentiated	38°4'5.2007" North (38.068111°)	122°49'22.7534" West (122.822987°)	MARIN	CA
55	WPOS0	Wetland: Undifferentiated	38°4'14.8134" North (38.070782°)	122°49'24.1779" West (122.823383°)	MARIN	CA
56	WPOS1	Wetland: Undifferentiated	38°4'23.011" North (38.073059°)	122°49'22.0198" West (122.822783°)	MARIN	CA

57	WPOS2	Wetland: Undifferentiated	38°4'32.3705" North (38.075658°)	122°49'32.9496" West (122.825819°)	MARIN	CA
58	WPPanne1	Wetland: Undifferentiated	38°4'46.763" North (38.079656°)	122°49'42.1502" West (122.828375°)	MARIN	CA
59	WPPanne2	Wetland: Undifferentiated	38°4'43.1459" North (38.078652°)	122°49'53.4572" West (122.831516°)	MARIN	CA
60	WPSeep	Wetland: Undifferentiated	38°4'30.6937" North (38.075193°)	122°49'46.4751" West (122.829576°)	MARIN	CA
61	WPTDCRK	Wetland: Undifferentiated	38°4'42.108" North (38.078363°)	122°49'53.614" West (122.831559°)	MARIN	CA

Stations filtered for:
Organization = TBWC: Tomales Bay Watershed Council
Project = GWRP: Giacomini Wetland Restoration Project WQ Monitoring

Appendix C -
WY08, WY09, WY10 and WY11 Station Visit and Result Summary Tables

The tables below were originally included in the body of the respective annual water quality report (Carson 2009, Carson2010 and Carson 2011) which are available online at: http://www.tomalesbaywatershed.org/informationreports.html
The tables summarize Trends Program sampling events for each water year as well as the means and ranges of data collected for the 2007-08, 2008-09, 2009-10 and 2010-11 water years.

List of Tables:

Table C1 – Summary of Trends Program Sampling Events for 2007-2008 Water Year

WY08 Site Visit Summary

Site Name	Site Type	Description	Period of Record	Number of Samples
Lagunitas Creek				
SG1	Tributary Site	San Geronimo Creek at Lagunitas Rd	12/17/07-9/30/08	28
LAGSPT	Mainstem Stream Site	Lagunitas Creek in SPT State Park (at USGS streamgage)	12/17/07-9/30/08	28
OLM11	Tributary Site	Olema Creek at NPS streamgage	12/17/07-9/30/08	28
LAG1	Mainstem Stream Site	Lagunitas Creek at Hwy. 1 (Green Bridge)	12/17/07-9/30/08	28
West Shore				
FV1	Mainstem Stream Site	First Valley Creek at SFD Blvd.	12/17/07-9/30/08	28
WG1	Mainstem Stream Site	White Gulch upstream of Bay inflow	12/17/07-6/10/08	20
East Shore				
MC1*	Mainstem Stream Site	Millerton Gulch at upstream CA State Park boundary*	3/18/08-4/22/08	5
MC1A*	Mainstem Stream Site	Millerton Gulch at Hwy. 1*	12/17/08-7/22/08	17
MP36.17	Mainstem Stream Site	Reference stream at Hwy. 1	1/2/08-9/30/08	27
Walker Creek				
WKR2	Mainstem Stream Site	Walker Creek at Walker Creek Ranch	1/22/08-9/30/08	24
WKR1	Mainstem Stream Site	Walker Creek at Hwy.1	12/17/07-9/30/08	28
KYS1	Tributary Site	Keys Creek at Hwy. 1	1/2/08-6/24/08	20
Tomales Bay Sites				
TB2	Outer Bay Site	Bay Site near Walker Crk input	12/18/08-9/16/08	24
TB4	Mid-Bay Site	Bay Site North of Marshall	12/18/08-9/16/08	24
TB11	Inner Bay Site	Bay site near Millerton Point	12/18/08-9/16/08	27
LAG6	Wetlands/Bay Interface	Lagunitas Creek downstream of levees	1/29/08-9/30/08	21

* Millerton Gulch sampling site was moved upstream from Hwy. 1 sampling site to eliminate tidal influence.

Table C2 – Summary of Trends Program Sampling Events for 2008-2009 Water Year

WY09 Site Visit Summary

Site Name	Site Type	Description	Period of Record	Number of Samples
Lagunitas Creek				
SG1	Tributary Site	San Geronimo Creek at Lagunitas Rd	10/14/08-9/15/09	33
LAGSPT	Mainstem Stream Site	Lagunitas Creek in SPT State Park (at USGS streamgage)	10/14/08-9/15/09	33
OLM11	Tributary Site	Olema Creek at NPS streamgage	10/14/08-9/15/09	33
LAG1	Mainstem Stream Site	Lagunitas Creek at Hwy. 1 (Green Bridge)	10/14/08-9/15/09	33
West Shore				
FV1	Mainstem Stream Site	First Valley Creek at SFD Blvd.	10/14/08-9/15/09	33
WG1	Mainstem Stream Site	White Gulch upstream of Bay inflow	12/16/08-3/24/09	10
East Shore				
MC1	Mainstem Stream Site	Millerton Gulch at upstream CA State Park boundary	12/30/08-6/16/09	19
MP36.17	Mainstem Stream Site	Reference stream at Hwy. 1	10/14/08-9/15/09	33
Walker Creek				
WKR2	Mainstem Stream Site	Walker Creek at Walker Creek Ranch	10/14/08-9/15/09	33
WKR1	Mainstem Stream Site	Walker Creek at Hwy.1	10/14/08-9/15/09	33
KYS1	Tributary Site	Keys Creek at Hwy. 1	11/4/08-5/5/09	16
Tomales Bay Sites				
TB2	Outer Bay Site	Bay Site near Walker Crk input	10/14/08-9/1/09	13
TB4	Mid-Bay Site	Bay Site North of Marshall	10/14/08-9/1/09	13
TB11	Inner Bay Site	Bay site near Millerton Point	10/14/08-9/1/09	20
LAG6	Wetlands/Bay Interface	Lagunitas Creek downstream of levees	11/4/08-9/15/09	28

Table C3 – Summary of Trends Program Sampling Events for 2009-2010 Water Year

		WY10 Site Visit Summary		
Site Name	Site Type	Description	Period of Record	Number of Samples
Lagunitas Creek				
SG1	Tributary Site	San Geronimo Creek at Lagunitas Rd	10/6/09-9/21/10	41
LAGSPT	Mainstem Stream Site	Lagunitas Creek in SPT State Park (at USGS streamgage)	10/6/09-9/21/10	41
OLM11	Tributary Site	Olema Creek at NPS streamgage	10/6/09-9/21/10	41
LAG1	Mainstem Stream Site	Lagunitas Creek at Hwy. 1 (Green Bridge)	10/6/09-9/21/10	41
West Shore				
FV1	Mainstem Stream Site	First Valley Creek at SFD Blvd.	10/6/09-9/21/10	41
WG1	Mainstem Stream Site	White Gulch upstream of Bay inflow	10/13/09-9/21/10	32
East Shore				
MC1	Mainstem Stream Site	Millerton Gulch at upstream CA State Park boundary	10/13/09-08/17/10	38
MP36.17	Mainstem Stream Site	Reference stream at Hwy. 1	10/6/09-9/21/10	41
Walker Creek				
WKR2	Mainstem Stream Site	Walker Creek at Walker Creek Ranch	10/6/09-9/21/10	41
WKR1	Mainstem Stream Site	Walker Creek at Hwy.1	10/6/09-9/21/10	41
KYS1	Tributary Site	Keys Creek at Hwy. 1	10/13/09-08/17/10	37
Tomales Bay Sites				
TB2	Outer Bay Site	Bay Site near Walker Crk input	10/6/09-09/07/10	9
TB4	Mid-Bay Site	Bay Site North of Marshall	10/6/09-09/07/10	9
TB11	Inner Bay Site	Bay site near Millerton Point	10/6/09-09/07/10	9
LAG6	Wetlands/Bay Interface	Lagunitas Creek downstream of levees	10/6/09-9/21/10	41

Table C4 – Summary of Trends Program Sampling Events for 2010-2011 Water Year

		WY11 Site Visit Summary		
Site Name	Site Type	Description	Period of Record	Number of Sampling Visits
Lagunitas Creek				
SG1	Tributary Site	San Geronimo Creek at Lagunitas Rd	10/5/10-9/20/11	38
LAGSPT	Mainstem Stream Site	Lagunitas Creek in SPT State Park (at USGS streamgage)	10/5/10-9/20/11	38
OLM11	Tributary Site	Olema Creek at NPS streamgage	10/5/10-9/20/11	38
LAG1	Mainstem Stream Site	Lagunitas Creek at Hwy. 1 (Green Bridge)	10/5/10-9/20/11	38
West Shore				
FV1	Mainstem Stream Site	First Valley Creek at SFD Blvd.	10/5/10-9/20/11	38
WG1	Mainstem Stream Site	White Gulch upstream of Bay inflow	10/26/10-8/15/11	34
East Shore				
MC1	Mainstem Stream Site	Millerton Gulch at upstream CA State Park boundary	11/9/10-8/15/11	32
MP36.17	Mainstem Stream Site	Reference stream at Hwy. 1	10/5/10-9/20/11	38
Walker Creek				
WKR2	Mainstem Stream Site	Walker Creek at Walker Creek Ranch	10/5/10-9/20/11	38
WKR1	Mainstem Stream Site	Walker Creek at Hwy.1	10/5/10-9/20/11	38
KYS1	Tributary Site	Keys Creek at Hwy. 1	10/26/10-9/20/11	35
Tomales Bay Sites				
TB2	Outer Bay Site	Bay Site near Walker Crk input	10/5/10-9/6/11	10
TB4	Mid-Bay Site	Bay Site North of Marshall	10/5/10-9/6/11	10
TB11	Inner Bay Site	Bay site near Millerton Point	10/5/10-9/6/11	6
LAG6	Wetlands/Bay Interface	Lagunitas Creek downstream of levees	10/5/10-9/20/11	36

Table C5 – Summary of Trends Program Field Parameter Results for WY08

WY08 Field Parameter Results

Site Name	# of Samples	Water Temp °C			Specific Conductance (µS/cm)			Salinity (ppth)			Dissolved Oxygen (mg/L)			pH		
		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Lagunitas Creek																
SG1	28	6	16.8	10.38	58.1	394.7	315.6	0.0	0.2	0.154	5.57	11.2	9.273	7	8.01	7.68
LAGSPT	28	8	14.3	9.99	154.9	340.9	195.9	0.1	0.2	0.104	9.15	11.29	10.22	7.07	8.18	7.75
OLM11	27	7.1	16.1	10.76	130.8	333	244.2	0.1	0.2	0.119	7.67	12.03	9.79	7.19	7.77	7.49
LAG1	28	7.1	18.8	12.01	147.4	1822	537.8	0.1	0.9	0.27	6.65	10.85	8.76	6.47	7.82	7.23
West Shore																
FV1	28	8.1	15.1	11.14	130.8	210.7	171	0.1	0.1	0.1	7.38	11.84	10.31	6.97	7.87	7.24
WG1	20	7.3	20.6	10.76	233.1	5690	647.4	0.1	3.1	0.335	2.01	10.68	9.1	6.43	7.17	6.98
East Shore																
MC1	5	9	10.5	9.74	240.7	283.9	266.7	0.1	0.1	0.1	5.26	9.19	7.45	6.34	6.81	6.61
MC1A**	17	7	19.5	11.01	151.3	41800	13219	0.1	26.9	8.31	3.4	11.15	8.71	7.06	7.81	7.31
MP36.17	27	7.2	15.3	11.06	127	335.6	243	0.1	0.2	0.115	9.05	11.63	10.19	7.19	7.95	7.53
Walker Creek																
WKR2	24	8.3	16.3	11.69	130.5	185.2	145	0.1	0.1	0.1	8.86	11.85	10.18	6.92	7.69	7.26
WKR1	28	7	21.7	12.98	143.2	18230	2187	0.1	10.8	1.218	6.46	10.98	9.147	6.98	7.8	7.39
KYS1	20	6.7	14.5	10.45	167.4	460.3	308.9	0.1	0.2	0.15	6.47	11.29	9.416	7.03	7.56	7.21
Tomales Bay Sites																
TB2	22	8.7	18.3	12.72	*	*	*	16	41	35.71	*	*	*	*	*	*
TB4	22	8.8	18.2	13.71	*	*	*	16	42	34.75	*	*	*	*	*	*
TB11	23	7.8	16.7	12.51	*	*	*	*	*	*	*	*	*	*	*	*
LAG6	21	9	24.9	16.04	220.9	40690	13173	0.1	26.1	7.82	6.17	14.68	8.79	7.27	8.8	7.78

* Parameter not collected or analzed for this site

**Millerton Gulch sampling site was moved upstream during this water year to eliminate tidal influence.

MC1A refers to sampling site at Shoreline Hwy bridge, MC1 is upstream site.

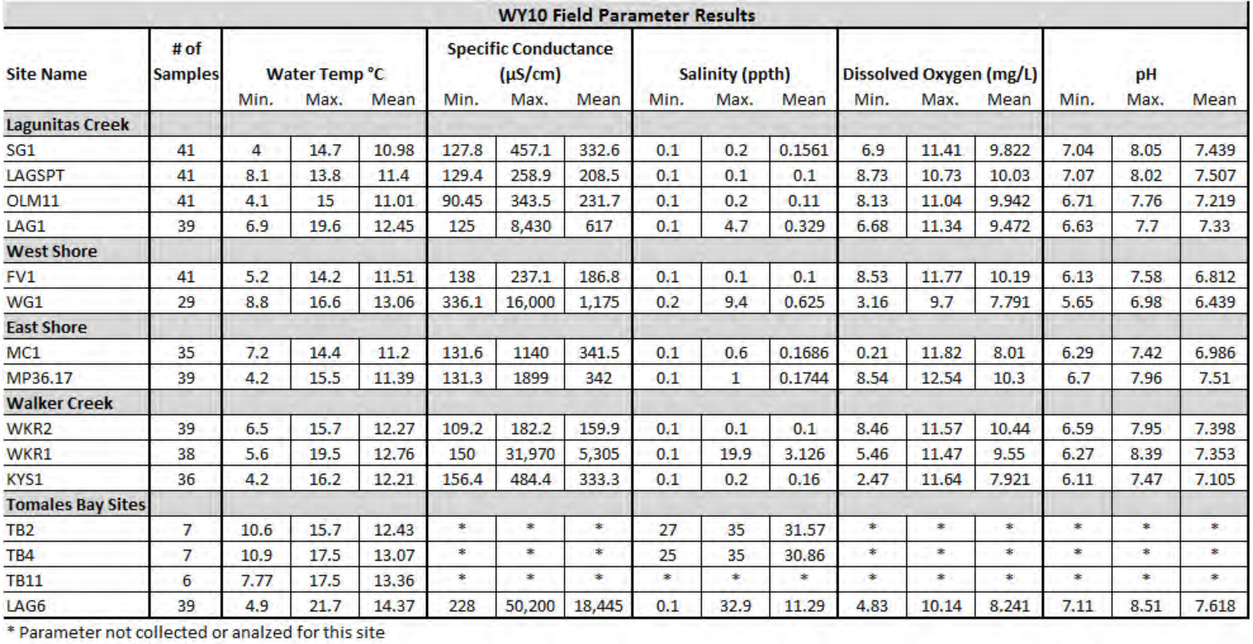
Table C6 – Summary of Trends Program Field Parameter Results for WY09

WY09 Field Parameter Results

Site Name	# of Samples	Water Temp °C			Specific Conductance (µS/cm)			Salinity (ppth)			Dissolved Oxygen (mg/L)			pH		
		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Lagunitas Creek																
SG1	33	5.1	15.4	10.43	147.4	514	380.5	0.1	0.2	0.1818	5.95	11.45	9.311	7.05	8.14	7.685
LAGSPT	33	7.5	13.8	10.48	144.9	238.1	183.3	0.1	0.1	0.1	8.55	11.36	10.25	7.23	8.12	7.722
OLM11	33	4.6	16.2	10.49	114.5	360.5	286.3	0.1	0.2	0.1545	7.76	11.84	9.573	7.17	7.95	7.494
LAG1	33	7.1	19.1	12.25	147.3	6,480	1,075	0.1	3.6	0.5625	6.54	11.74	9.055	6.4	7.8	7.15
West Shore																
FV1	33	5.8	15.3	10.76	161.5	246.5	207.9	0.1	0.1	0.1	9.12	12.72	10.24	5.75	7.62	6.985
WG1	10	7.6	13.3	10.14	186.3	45,540	7,200	0.1	29.3	4.543	7.18	9.12	8.22	4.89	7.71	6.165
East Shore																
MC1	19	5.6	13.4	9.421	152.4	445.6	323.8	0.1	0.2	0.1632	0.73	12.03	7.626	6.78	7.44	7.144
MP36.17	33	5.3	15.1	10.83	171.1	621	325.2	0.1	0.3	0.1727	7.48	12.51	10.17	6.81	8.05	7.674
Walker Creek																
WKR2	33	6.9	15.7	11.66	128.4	192.2	157.9	0.1	0.1	0.1	9.08	12.27	10.2	6.99	8.01	7.395
WKR1	33	5.5	19.3	12.42	150.8	24,460	8,274	0.1	14.9	4.778	6.31	11.26	8.965	6.9	8.09	7.576
KYS1	15	4.9	14.6	9.113	116.1	517	380.4	0.1	0.2	0.18	4	11.49	8.019	6.7	7.69	7.218
Tomales Bay Sites																
TB2	11	9.4	17.8	13.29	*	*	*	35	45	36.5	*	*	*	*	*	*
TB4	11	9.3	17.9	14.15	*	*	*	35	45	36.5	*	*	*	*	*	*
TB11	12	7.2	16.7	10.92	*	*	*	*	*	*	*	*	*	*	*	*
LAG6	28	5.8	24.5	13.9	202.4	50,400	25,987	0.1	33.1	16.27	3.78	11.57	7.375	6.94	8.27	7.57

* Parameter not collected or analzed for this site

Table C7 – Summary of Trends Program Field Parameter Results for WY10

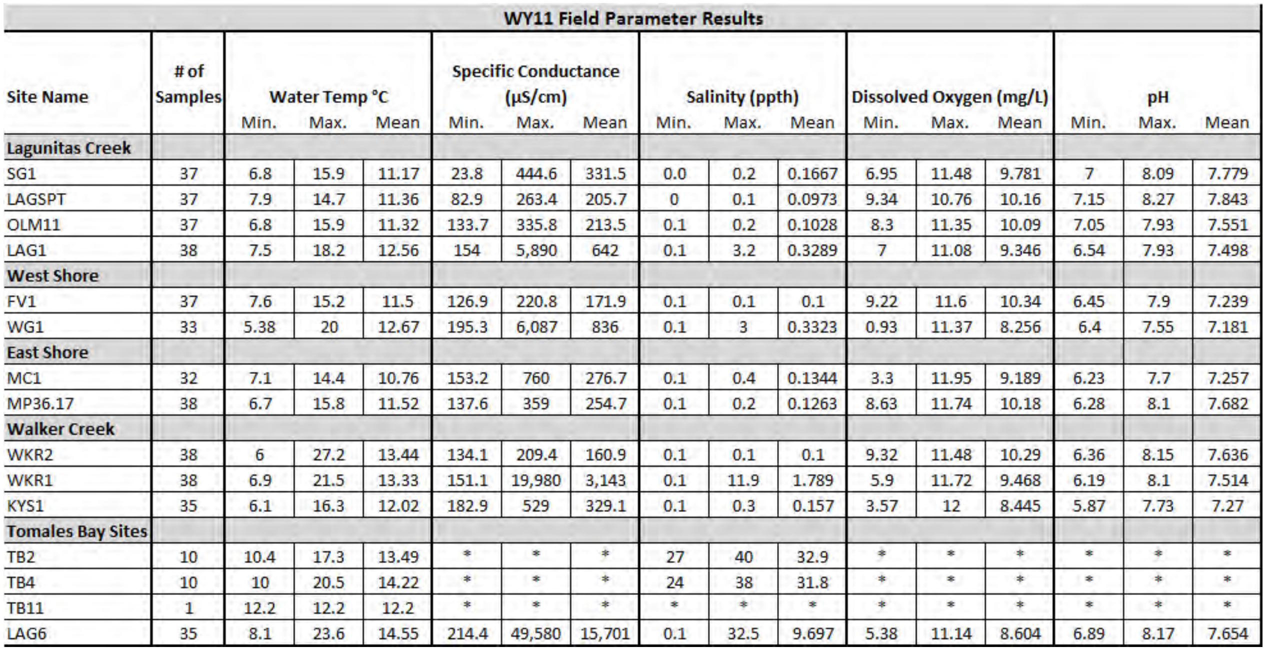


WY10 Field Parameter Results

Site Name	# of Samples	Water Temp °C			Specific Conductance (µS/cm)			Salinity (ppth)			Dissolved Oxygen (mg/L)			pH		
		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Lagunitas Creek																
SG1	41	4	14.7	10.98	127.8	457.1	332.6	0.1	0.2	0.1561	6.9	11.41	9.822	7.04	8.05	7.439
LAGSPT	41	8.1	13.8	11.4	129.4	258.9	208.5	0.1	0.1	0.1	8.73	10.73	10.03	7.07	8.02	7.507
OLM11	41	4.1	15	11.01	90.45	343.5	231.7	0.1	0.2	0.11	8.13	11.04	9.942	6.71	7.76	7.219
LAG1	39	6.9	19.6	12.45	125	8,430	617	0.1	4.7	0.329	6.68	11.34	9.472	6.63	7.7	7.33
West Shore																
FV1	41	5.2	14.2	11.51	138	237.1	186.8	0.1	0.1	0.1	8.53	11.77	10.19	6.13	7.58	6.812
WG1	29	8.8	16.6	13.06	336.1	16,000	1,175	0.2	9.4	0.625	3.16	9.7	7.791	5.65	6.98	6.439
East Shore																
MC1	35	7.2	14.4	11.2	131.6	1140	341.5	0.1	0.6	0.1686	0.21	11.82	8.01	6.29	7.42	6.986
MP36.17	39	4.2	15.5	11.39	131.3	1899	342	0.1	1	0.1744	8.54	12.54	10.3	6.7	7.96	7.51
Walker Creek																
WKR2	39	6.5	15.7	12.27	109.2	182.2	159.9	0.1	0.1	0.1	8.46	11.57	10.44	6.59	7.95	7.398
WKR1	38	5.6	19.5	12.76	150	31,970	5,305	0.1	19.9	3.126	5.46	11.47	9.55	6.27	8.39	7.353
KYS1	36	4.2	16.2	12.21	156.4	484.4	333.3	0.1	0.2	0.16	2.47	11.64	7.921	6.11	7.47	7.105
Tomales Bay Sites																
TB2	7	10.6	15.7	12.43	*	*	*	27	35	31.57	*	*	*	*	*	*
TB4	7	10.9	17.5	13.07	*	*	*	25	35	30.86	*	*	*	*	*	*
TB11	6	7.77	17.5	13.36	*	*	*	*	*	*	*	*	*	*	*	*
LAG6	39	4.9	21.7	14.37	228	50,200	18,445	0.1	32.9	11.29	4.83	10.14	8.241	7.11	8.51	7.618

* Parameter not collected or analzed for this site

Table C8 – Summary of Trends Program Field Parameter Results for WY11



WY11 Field Parameter Results

Site Name	# of Samples	Water Temp °C			Specific Conductance (µS/cm)			Salinity (ppth)			Dissolved Oxygen (mg/L)			pH		
		Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Lagunitas Creek																
SG1	37	6.8	15.9	11.17	23.8	444.6	331.5	0.0	0.2	0.1667	6.95	11.48	9.781	7	8.09	7.779
LAGSPT	37	7.9	14.7	11.36	82.9	263.4	205.7	0	0.1	0.0973	9.34	10.76	10.16	7.15	8.27	7.843
OLM11	37	6.8	15.9	11.32	133.7	335.8	213.5	0.1	0.2	0.1028	8.3	11.35	10.09	7.05	7.93	7.551
LAG1	38	7.5	18.2	12.56	154	5,890	642	0.1	3.2	0.3289	7	11.08	9.346	6.54	7.93	7.498
West Shore																
FV1	37	7.6	15.2	11.5	126.9	220.8	171.9	0.1	0.1	0.1	9.22	11.6	10.34	6.45	7.9	7.239
WG1	33	5.38	20	12.67	195.3	6,087	836	0.1	3	0.3323	0.93	11.37	8.256	6.4	7.55	7.181
East Shore																
MC1	32	7.1	14.4	10.76	153.2	760	276.7	0.1	0.4	0.1344	3.3	11.95	9.189	6.23	7.7	7.257
MP36.17	38	6.7	15.8	11.52	137.6	359	254.7	0.1	0.2	0.1263	8.63	11.74	10.18	6.28	8.1	7.682
Walker Creek																
WKR2	38	6	27.2	13.44	134.1	209.4	160.9	0.1	0.1	0.1	9.32	11.48	10.29	6.36	8.15	7.636
WKR1	38	6.9	21.5	13.33	151.1	19,980	3,143	0.1	11.9	1.789	5.9	11.72	9.468	6.19	8.1	7.514
KYS1	35	6.1	16.3	12.02	182.9	529	329.1	0.1	0.3	0.157	3.57	12	8.445	5.87	7.73	7.27
Tomales Bay Sites																
TB2	10	10.4	17.3	13.49	*	*	*	27	40	32.9	*	*	*	*	*	*
TB4	10	10	20.5	14.22	*	*	*	24	38	31.8	*	*	*	*	*	*
TB11	1	12.2	12.2	12.2	*	*	*	*	*	*	*	*	*	*	*	*
LAG6	35	8.1	23.6	14.55	214.4	49,580	15,701	0.1	32.5	9.697	5.38	11.14	8.604	6.89	8.17	7.654

Table C9 – Summary of Trends Program Nutrient Parameter Results for WY08

	WY08 Nutrient Results																			
	Nitrate as N (mg/L)					Total Kjeldahl Nitrogen (mg/L)					Ammonia as N (mg/L)					Total Phosphorus (mg/L)				
Site Name	# of detections	# of non-detects†	Min.	Max.	Mean	# of detections	# of non-detects†	Min.	Max.	Mean	# of detections	# of non-detects†	Min.	Max.	Mean	# of detections	# of non-detects†	Min.	Max.	Mean
Lagunitas Creek																				
SG1	22	6	<0.11	1.807	0.456	16	12	<0.25	0.79	0.344	1	27	<0.082	0.099	†	0	27	<0.1	<0.1	†
LAGSPT	17	11	<0.11	0.723	0.224	10	18	<0.25	0.82	†	0	28	<0.082	<0.082	†	0	27	<0.1	<0.1	†
OLM11	16	11	<0.11	0.655	0.252	17	10	<0.25	0.72	0.355	0	27	<0.082	<0.082	†	4	23	<0.1	0.14	†
LAG1	12	16	<0.11	0.565	†	16	12	<0.25	0.56	0.326	0	0	<0.082	<0.082	†	1	26	<0.10	0.13	†
West Shore																				
FV1	27	1	<0.11	0.678	0.252	17	11	<0.25	0.53	0.331	0	28	<0.082	<0.082	†	0	27	<0.10	<0.10	†
WG1	1	19	<0.11	0.208	†	17	3	<0.25	1.5	0.474	1	19	<0.082	0.165	†	2	17	<0.1	0.18	†
East Shore																				
MC1	4	1	<0.11	0.271	0.197	4	1	<0.25	0.49	0.336	0	5	<0.082	<0.082	†	0	27	<0.1	<0.1	†
MC1A*	10	7	<0.11	1.717	0.469	14	3	<0.25	1.3	0.511	0	17	<0.082	<0.082	†	3	13	<0.1	0.19	†
MP36.17	6	21	<0.11	0.384	†	23	4	<0.25	0.76	0.392	0	27	<0.082	<0.082	†	0	26	<0.1	<0.1	†
Walker Creek																				
WKR2	23	1	<0.11	0.407	0.262	20	4	<0.25	1.1	0.549	0	24	<0.082	<0.082	†	12	12	<0.10	0.28	0.126
WKR1	11	17	<0.11	0.836	†	26	2	<0.25	0.96	0.516	1	27	<0.082	0.13	†	9	18	<0.1	0.26	†
KYS1	16	4	<0.11	1.152	0.444	20	0	0.25	1.7	0.676	1	9	<0.082	0.107	†	2	17	<0.1	0.11	†
Tomales Bay Sites																				
TB2	1	23	<0.11	0.294	†	16	8	<0.25	1.2	0.449	0	24	<0.082	<0.082	†	8	15	<0.1	0.31	†
TB4	1	23	<0.11	0.384	†	16	8	<0.25	1.2	0.408	0	24	<0.082	<0.082	†	5	18	<0.1	0.15	†
TB11	1	26	<0.11	0.452	†	20	7	<0.25	0.99	0.398	0	27	<0.082	<0.082	†	9	17	<0.1	0.29	†
LAG6	7	14	<0.11	0.339	†	17	4	<0.25	2.4	0.622	1	20	<0.082	0.559	†	6	15	<0.1	0.49	†

*Millerton Gulch sampling site was moved upstream during this water year to eliminate tidal influence.
MC1A refers to sampling site at Shoreline Hwy bridge, MC1 is upstream site.

† Censored data (<QL: *non-detects) handled by Kaplan Meier Method which cannot estimate a mean if more than 50% of data is censored.

Table C10 – Summary of Trends Program Nutrient Parameter Results for WY09

	WY09 Nutrient Results																			
	Nitrate as N (mg/L)					Total Kjeldahl Nitrogen (mg/L)					Ammonia as N (mg/L)					Total Phosphorus (mg/L)				
Site Name	# of detections	# of non-detects†	Min.	Max.	Mean	# of detections	# of non-detects†	Min.	Max.	Mean	# of detections	# of non-detects†	Min.	Max.	Mean	# of detections	# of non-detects†	Min.	Max.	Mean
Lagunitas Creek																				
SG1	30	2	<0.11	1.626	0.642	27	6	<0.25	5.3	1.004	0	0	<0.082	<0.493	†	3	30	<0.05	<0.10	†
LAGSPT	15	18	<0.11	0.772	†	22	11	<0.25	5.9	0.939	0	33	<0.082	<0.493	†	1	32	<0.05	<0.1	†
OLM11	16	17	<0.11	1.062	†	23	10	<0.25	5.3	0.908	0	33	<0.082	<0.493	†	5	28	<0.05	0.13	†
LAG1	11	22	<0.11	0.858	†	21	12	<0.25	5.3	0.979	0	33	<0.082	<0.082	†	1	32	<0.05	<0.10	†
West Shore																				
FV1	24	9	<0.11	1.468	0.302	24	9	<0.25	6.7	1.073	0	33	<0.082	<0.082	†	2	31	<0.05	<0.10	†
WG1	4	5	<0.11	2.485	†	9	0	0.33	15	2.633	0	9	<0.082	<0.493	†	2	7	<0.05	0.11	†
East Shore																				
MC1	9	10	<0.11	1.649	†	16	3	0.3	5.9	1.659	0	19	<0.082	<0.493	†	3	16	<0.05	<0.10	†
MP36.17	5	28	<0.11	0.429	†	29	4	<0.25	7.6	1.093	0	33	<0.082	<0.493	†	1	32	<0.05	<0.1	†
Walker Creek																				
WKR2	27	6	<0.11	5.873	0.396	30	3	0.37	6.7	1.165	0	33	<0.082	<0.493	†	10	23	<0.05	0.19	†
WKR1	6	27	<0.11	1.062	†	31	2	0.3	4.2	1.078	0	33	<0.082	<0.493	†	11	22	<0.05	0.11	†
KYS1	15	1	<0.11	2.937	0.561	15	0	0.61	9	2.542	0	15	<0.082	<0.082	†	6	9	<0.05	0.22	†
Tomales Bay Sites																				
TB2	0	13	<0.11	<1.1	†	10	3	<0.25	1.4	0.51	1	12	<0.082	<0.493	†	1	12	<0.05	<0.10	†
TB4	0	13	<0.11	<1.1	†	9	4	<0.25	1.7	0.565	0	13	<0.082	<0.493	†	1	12	<0.05	<0.1	†
TB11	2	18	<0.11	1.401	†	18	2	<0.25	4.2	0.891	0	20	<0.082	<0.493	†	2	18	<0.05	0.11	†
LAG6	5	23	<0.11	<1.1	†	24	4	0.28	8.4	1.41	1	27	<0.1	<0.6	†	10	18	<0.05	0.12	†

† Censored data (<QL: *non-detects) handled by Kaplan Meier Method which cannot estimate a mean if more than 50% of data is censored.

Table C11 – Summary of Trends Program Nutrient Parameter Results for WY10

WY10 Nutrient Results

	Nitrate as N (mg/L)					Total Kjeldahl Nitrogen (mg/L)					Ammonia as N (mg/L)					Total Phosphorus (mg/L)				
Site Name	# of detections	# of non-detects†	Min.	Max.	Mean	# of detections	# of non-detects†	Min.	Max.	Mean	# of detections	# of non-detects†	Min.	Max.	Mean	# of detections	# of non-detects†	Min.	Max.	Mean
Lagunitas Creek																				
SG1	40	1	<0.11	1.423	0.54	40	1	<0.25	3.9	0.672	1	40	<0.082	0.107	†	4	37	<0.1	0.4	†
LAGSPT	35	6	<0.11	0.881	0.22	39	2	<0.25	1.3	0.48	0	41	<0.082	<0.082	†	2	39	<0.1	0.23	†
OLM11	34	7	<0.11	0.678	0.269	39	2	<0.25	4.7	0.67	0	41	<0.082	<0.082	†	4	37	<0.1	0.31	†
LAG1	23	18	<0.11	0.678	0.198	38	3	<0.25	2.9	0.582	0	41	<0.082	<0.082	†	1	40	<0.05	0.36	†
West Shore																				
FV1	36	5	<0.11	1.175	0.256	41	0	0.25	4.9	0.581	1	40	<0.082	<0.10	†	1	40	<0.10	0.37	†
WG1	5	24	<0.11	0.858	†	29	0	0.48	3.7	1.009	1	28	<0.082	0.206	†	5	24	<0.05	0.82	†
East Shore																				
MC1	26	9	<0.11	1.175	0.399	34	1	<0.25	39	2.109	11	24	<0.082	10.69	†	6	29	<0.05	2.9	†
MP36.17	8	33	<0.11	0.316	†	41	0	0.27	1.8	0.566	0	41	<0.082	<0.082	†	1	40	<0.1	0.13	†
Walker Creek																				
WKR2	31	10	<0.11	0.497	0.219	41	0	0.42	5.8	0.926	1	40	<0.082	0.082	†	9	32	<0.05	0.77	†
WKR1	20	21	<0.0565	<1.1	†	41	0	0.4	2.5	0.943	7	34	<0.082	0.247	†	12	29	<0.1	0.34	†
KYS1	24	12	<0.11	2.485	0.336	36	0	0.64	2.1	1.169	2	34	<0.082	0.239	†	7	29	<0.05	0.5	†
Tomales Bay Sites																				
TB2	1	8	<0.11	<1.13	†	8	1	<0.25	0.69	0.417	0	9	<0.082	<0.082	†	1	8	<0.1	0.12	†
TB4	1	8	<0.11	<1.13	†	8	1	<0.25	0.94	0.559	0	9	<0.082	<0.082	†	1	8	<0.1	0.12	†
TB11	1	8	<0.11	<1.13	†	9	0	0.41	0.57	0.491	0	9	<0.082	<0.082	†	2	7	<0.1	0.18	†
LAG6	13	27	<0.0452	<1.13	†	40	0	0.34	1.6	0.679	5	35	<0.082	0.148	†	5	35	<0.05	0.16	†

† Censored data (<QL: *non-detects) handled by Kaplan Meier Method which cannot estimate a mean if more than 50% of data is censored.

Table C12 – Summary of Trends Program Nutrient Parameter Results for WY11

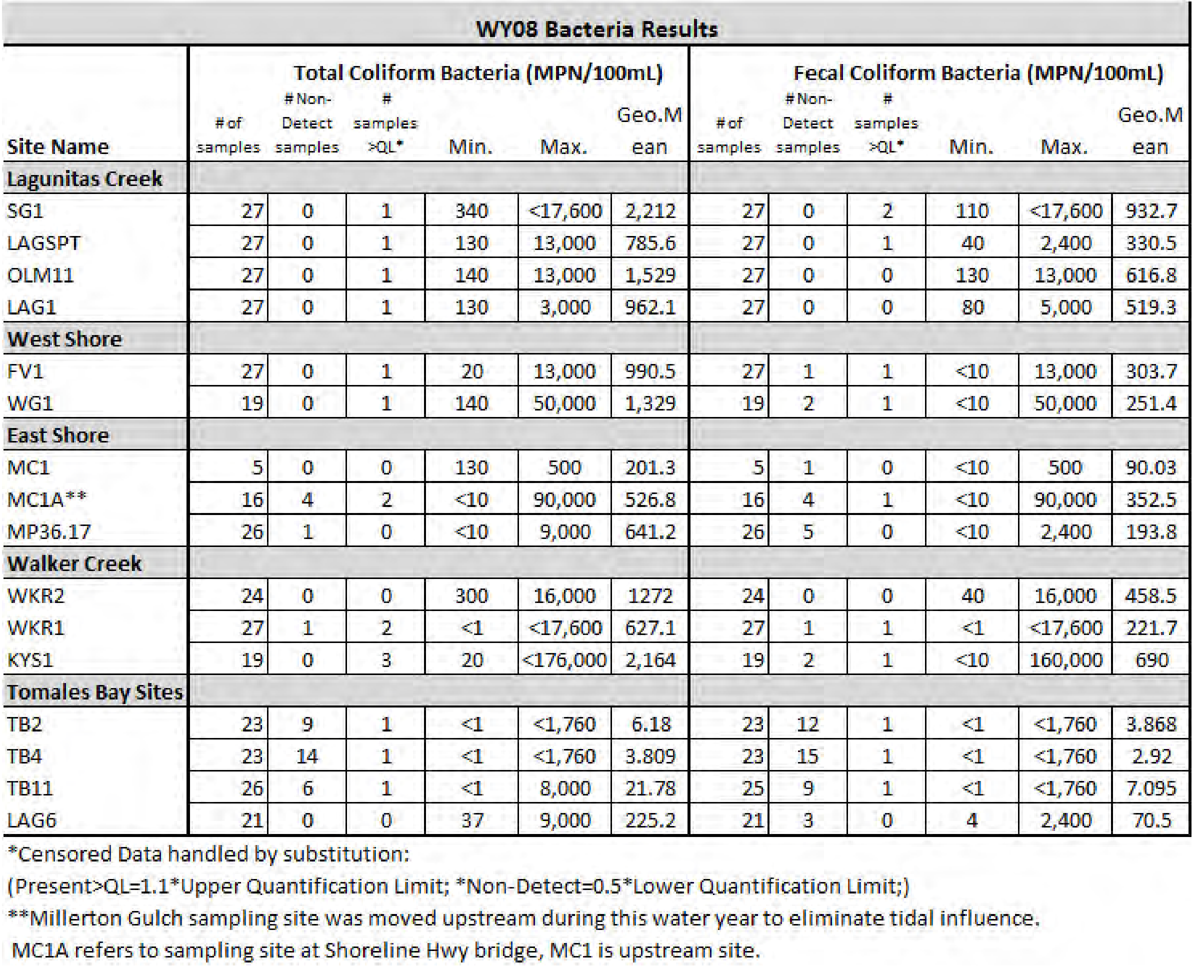
WY11 Nutrient Results

	Nitrate as N (mg/L)					Total Kjeldahl Nitrogen (mg/L)					Ammonia as N (mg/L)**				
Site Name	# of detections	# of non-detects†	Min.	Max.	Mean	# of detections	# of non-detects†	Min.	Max.	Mean	# of detections	# of non-detects†	Min.	Max.	Mean
Lagunitas Creek															
SG1	38	0	0.1559	1.694	0.535	36	2	<0.25	0.74	0.45	0	1	<0.082	<0.082	†
LAGSPT	23	15	<0.11	0.723	0.216	37	1	<0.25	0.71	0.394	0	1	<0.082	<0.082	†
OLM11	33	5	<0.11	0.723	0.312	38	0	0.25	0.85	0.479	0	1	<0.082	<0.082	†
LAG1	23	15	<0.11	0.858	0.214	37	1	<0.25	1.1	0.475	0	1	<0.082	<0.082	†
West Shore															
FV1	28	10	<0.11	0.836	0.241	38	0	0.26	0.71	0.405	0	1	<0.082	<0.082	†
WG1	3	31	<0.11	0.407	†	34	0	0.55	1.7	0.881	0	1	<0.082	<0.082	†
East Shore															
MC1	18	14	<0.11	1.22	0.352	32	0	0.28	1.4	0.543	0	0			†
MP36.17	6	32	<0.11	0.384	†	38	0	0.26	1.4	0.45	0	1	<0.082	<0.082	†
Walker Creek															
WKR2	32	6	<0.11	0.836	0.245	38	0	0.47	1.1	0.675	0	1	<0.082	<0.082	†
WKR1	23	15	<0.11	0.949	0.294	38	0	0.37	1.2	0.797	1	0	0.082	0.082	†
KYS1	30	5	<0.11	3.389	0.618	35	0	0.57	2	1.072	0	1	<0.082	<0.082	†
Tomales Bay Sites															
TB2	2	8	<0.11	0.156	†	10	0	0.38	1.2	0.598	0	0			†
TB4	1	8	<0.11	0.136	†	9	0	0.45	0.7	0.548	0	0			†
TB11	0	6	<0.11	<1.13	†	6	0	0.41	0.73	0.592	0	0			†
LAG6	16	20	<0.11	0.542	†	36	0	0.33	1.1	0.611	0	1	0.091	0.091	†

† Censored data (<QL: *non-detects) handled by Kaplan Meier Method which cannot estimate a mean if more than 50% of data is censored.

**Ammonia levels were analyzed during one event in WY11 before the program dropped the analysis due to >90% non-detects (WY08-WY10).

Table C13 – Summary of Trends Program Bacteria Parameter Results for WY08



WY08 Bacteria Results

Site Name	Total Coliform Bacteria (MPN/100mL) # of samples	# Non-Detect samples	# samples >QL*	Min.	Max.	Geo.Mean	Fecal Coliform Bacteria (MPN/100mL) # of samples	# Non-Detect samples	# samples >QL*	Min.	Max.	Geo.Mean
Lagunitas Creek												
SG1	27	0	1	340	<17,600	2,212	27	0	2	110	<17,600	932.7
LAGSPT	27	0	1	130	13,000	785.6	27	0	1	40	2,400	330.5
OLM11	27	0	1	140	13,000	1,529	27	0	0	130	13,000	616.8
LAG1	27	0	1	130	3,000	962.1	27	0	0	80	5,000	519.3
West Shore												
FV1	27	0	1	20	13,000	990.5	27	1	1	<10	13,000	303.7
WG1	19	0	1	140	50,000	1,329	19	2	1	<10	50,000	251.4
East Shore												
MC1	5	0	0	130	500	201.3	5	1	0	<10	500	90.03
MC1A**	16	4	2	<10	90,000	526.8	16	4	1	<10	90,000	352.5
MP36.17	26	1	0	<10	9,000	641.2	26	5	0	<10	2,400	193.8
Walker Creek												
WKR2	24	0	0	300	16,000	1272	24	0	0	40	16,000	458.5
WKR1	27	1	2	<1	<17,600	627.1	27	1	1	<1	<17,600	221.7
KYS1	19	0	3	20	<176,000	2,164	19	2	1	<10	160,000	690
Tomales Bay Sites												
TB2	23	9	1	<1	<1,760	6.18	23	12	1	<1	<1,760	3.868
TB4	23	14	1	<1	<1,760	3.809	23	15	1	<1	<1,760	2.92
TB11	26	6	1	<1	8,000	21.78	25	9	1	<1	<1,760	7.095
LAG6	21	0	0	37	9,000	225.2	21	3	0	4	2,400	70.5

*Censored Data handled by substitution:
(Present>QL=1.1*Upper Quantification Limit; *Non-Detect=0.5*Lower Quantification Limit;)
**Millerton Gulch sampling site was moved upstream during this water year to eliminate tidal influence.
MC1A refers to sampling site at Shoreline Hwy bridge, MC1 is upstream site.

Table C14 – Summary of Trends Program Bacteria Parameter Results for WY09

WY09 Bacteria Results												
	Total Coliform Bacteria (MPN/100mL)						Fecal Coliform Bacteria (MPN/100mL)					
Site Name	# of samples	# Non-Detect samples	# samples >QL*	Min.	Max.	Geo.Mean	# of samples	# Non-Detect samples	# samples >QL*	Min.	Max.	Geo.Mean
Lagunitas Creek												
SG1	17	0	0	220	16,000	2,087	33	0	0	20	7,600	337.2
LAGSPT	17	0	0	110	2,800	608.8	33	0	0	5	4,000	87.64
OLM11	17	0	0	370	16,000	2,617	33	0	0	24	12,000	318
LAG1	17	0	0	130	5,000	894.4	33	0	0	14	800	137
West Shore												
FV1	16	0	1	1700	<17,600	4,546	32	0	0	20	2,400	215.6
WG1	4	0	1	5000	<17,600	8,471	9	0	0	2	16,000	121.2
East Shore												
MC1	3	0	0	20	2,900	237.2	19	1	0	5	4,000	52.64
MP36.17	17	0	0	180	16,000	1462	33	3	0	<1	2,400	46.29
Walker Creek												
WKR2	17	0	0	270	3,000	826.9	33	0	0	8	12,000	217
WKR1	17	0	0	40	5,000	404.7	33	2	0	<10	2,400	107
KYS1	5	0	2	500	<17,600	4,484	16	0	1	7	16,000	236
Tomales Bay Sites												
TB2	10	4	0	<1	1,600	7.035	13	6	0	<1	26	3.941
TB4	10	7	0	<1	37	1.767	13	10	0	<1	2	1.173
TB11	12	6	0	<1	27	3.024	20	7	0	<1	400	3.849
LAG6	13	2	0	<10	1,300	211.7	28	2	0	4	800	45.78

*Censored Data handled by substitution:

(Present>QL=1.1*Upper Quantification Limit; *Non-Detect=0.5*Lower Quantification Limit;)

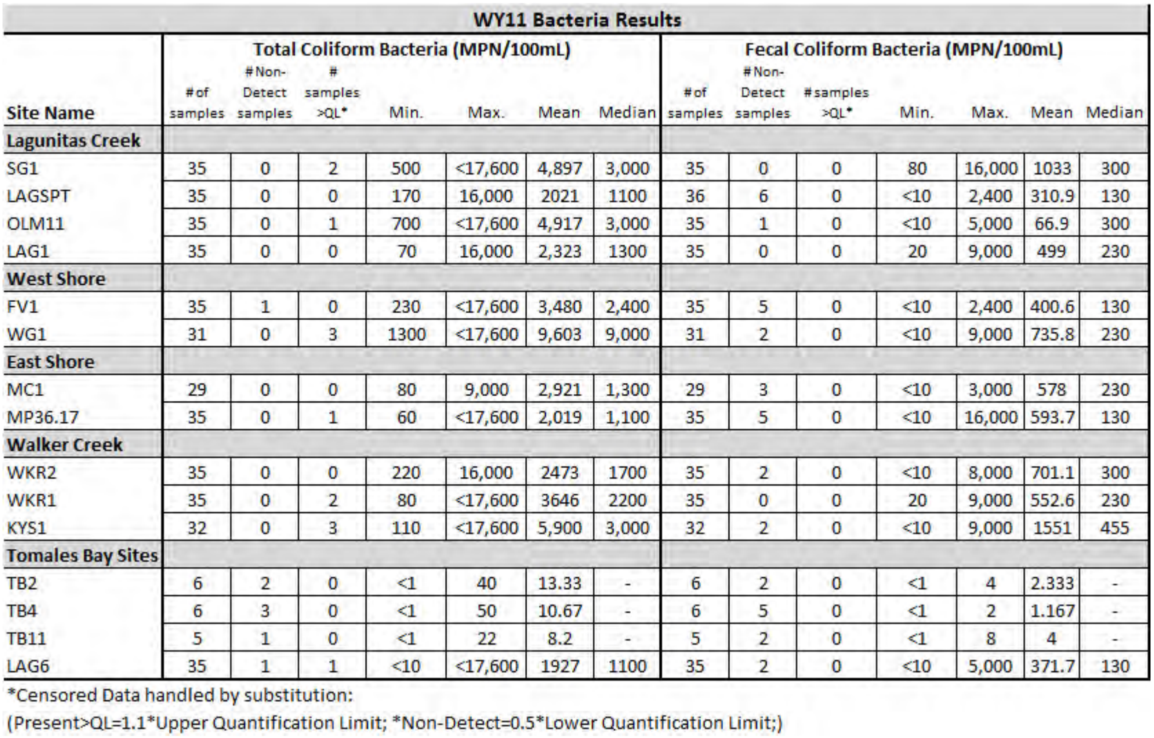
Table C15 – Summary of Trends Program Bacteria Parameter Results for WY10

WY10 Bacteria Results															
	Total Coliform Bacteria (MPN/100mL)							Fecal Coliform Bacteria (MPN/100mL)							
Site Name	# of samples	# Non-Detect samples	# samples >QL*	Min.	Max.	Mean	Median	# of samples	# Non-Detect samples	# samples >QL*	Min.	Max.	Mean	Median
Lagunitas Creek														
SG1	38	0	5	230	160,000	12,511	2,400	38	0	1	40	17,600	2212	600
LAGSPT	38	0	1	140	160,000	7585	1950	38	3	0	<10	16,000	978.4	230
OLM11	38	0	4	500	90,000	8,803	3,000	38	0	0	20	16,000	1930	300
LAG1	38	0	3	170	176,000	7,370	800	38	1	1	<10	17,600	1,378	230
West Shore														
FV1	38	0	1	270	24,000	4,892	2,400	34	4	0	<10	9,000	629.5	170
WG1	27	0	2	900	30,000	6,944	5,000	27	0	1	80	17,600	1976	300
East Shore														
MC1	32	0	4	130	30,000	6,680	1,300	32	2	2	<10	17,600	2,914	500
MP36.17	38	0	1	70	50,000	4,208	1,700	38	4	0	<10	16,000	969.7	230
Walker Creek														
WKR2	38	0	3	270	160,000	7976	1700	38	0	1	80	17,600	1885	400
WKR1	38	1	2	<10	90,000	6360	1300	38	4	0	<10	17,000	1167	230
KYS1	33	0	4	500	90,000	10,652	5,000	33	2	2	<10	17,600	2880	800
Tomales Bay Sites														
TB2	9	3	0	<1	23	8.444	4	9	4	0	<1	22	5.222	2
TB4	9	7	0	<1	11	2.444	1	9	7	0	<1	4	1.444	1
TB11	9	3	0	<1	30	8.333	2	9	5	0	<1	13	3.556	1
LAG6	37	4	1	<10	17,600	1478	340	37	9	0	<10	5,000	338.1	130

*Censored Data handled by substitution:

(Present>QL=1.1*Upper Quantification Limit; *Non-Detect=0.5*Lower Quantification Limit;)

Table C16 – Summary of Trends Program Bacteria Parameter Results for WY11

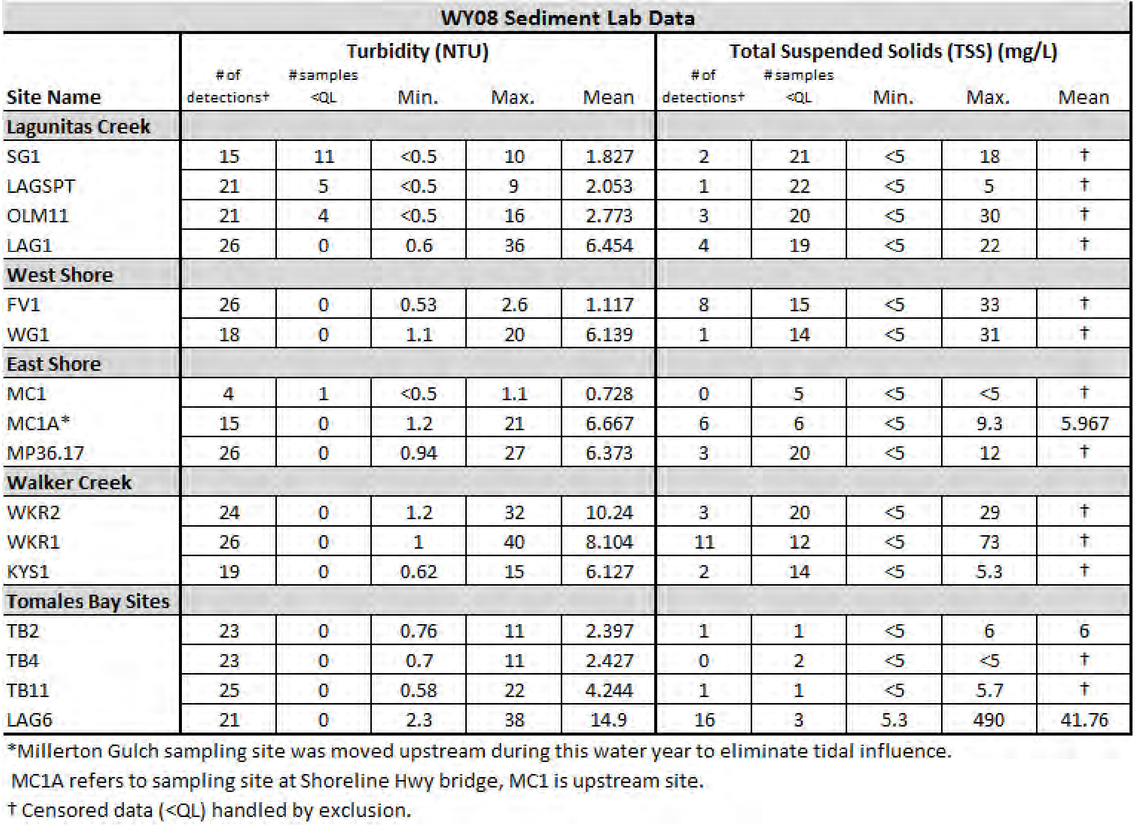


WY11 Bacteria Results

Site Name	Total Coliform Bacteria (MPN/100mL) # of samples	# Non-Detect samples	# samples >QL*	Min.	Max.	Mean	Median	Fecal Coliform Bacteria (MPN/100mL) # of samples	# Non-Detect samples	# samples >QL*	Min.	Max.	Mean	Median
Lagunitas Creek														
SG1	35	0	2	500	<17,600	4,897	3,000	35	0	0	80	16,000	1033	300
LAGSPT	35	0	0	170	16,000	2021	1100	36	6	0	<10	2,400	310.9	130
OLM11	35	0	1	700	<17,600	4,917	3,000	35	1	0	<10	5,000	66.9	300
LAG1	35	0	0	70	16,000	2,323	1300	35	0	0	20	9,000	499	230
West Shore														
FV1	35	1	0	230	<17,600	3,480	2,400	35	5	0	<10	2,400	400.6	130
WG1	31	0	3	1300	<17,600	9,603	9,000	31	2	0	<10	9,000	735.8	230
East Shore														
MC1	29	0	0	80	9,000	2,921	1,300	29	3	0	<10	3,000	578	230
MP36.17	35	0	1	60	<17,600	2,019	1,100	35	5	0	<10	16,000	593.7	130
Walker Creek														
WKR2	35	0	0	220	16,000	2473	1700	35	2	0	<10	8,000	701.1	300
WKR1	35	0	2	80	<17,600	3646	2200	35	0	0	20	9,000	552.6	230
KYS1	32	0	3	110	<17,600	5,900	3,000	32	2	0	<10	9,000	1551	455
Tomales Bay Sites														
TB2	6	2	0	<1	40	13.33	-	6	2	0	<1	4	2.333	-
TB4	6	3	0	<1	50	10.67	-	6	5	0	<1	2	1.167	-
TB11	5	1	0	<1	22	8.2	-	5	2	0	<1	8	4	-
LAG6	35	1	1	<10	<17,600	1927	1100	35	2	0	<10	5,000	371.7	130

*Censored Data handled by substitution:
(Present>QL=1.1*Upper Quantification Limit; *Non-Detect=0.5*Lower Quantification Limit;)

Table C17 – Summary of Trends Program Sediment Parameter Results for WY08



WY08 Sediment Lab Data

Site Name	Turbidity (NTU) # of detections†	# samples <QL	Min.	Max.	Mean	Total Suspended Solids (TSS) (mg/L) # of detections†	# samples <QL	Min.	Max.	Mean
Lagunitas Creek										
SG1	15	11	<0.5	10	1.827	2	21	<5	18	†
LAGSPT	21	5	<0.5	9	2.053	1	22	<5	5	†
OLM11	21	4	<0.5	16	2.773	3	20	<5	30	†
LAG1	26	0	0.6	36	6.454	4	19	<5	22	†
West Shore										
FV1	26	0	0.53	2.6	1.117	8	15	<5	33	†
WG1	18	0	1.1	20	6.139	1	14	<5	31	†
East Shore										
MC1	4	1	<0.5	1.1	0.728	0	5	<5	<5	†
MC1A*	15	0	1.2	21	6.667	6	6	<5	9.3	5.967
MP36.17	26	0	0.94	27	6.373	3	20	<5	12	†
Walker Creek										
WKR2	24	0	1.2	32	10.24	3	20	<5	29	†
WKR1	26	0	1	40	8.104	11	12	<5	73	†
KYS1	19	0	0.62	15	6.127	2	14	<5	5.3	†
Tomales Bay Sites										
TB2	23	0	0.76	11	2.397	1	1	<5	6	6
TB4	23	0	0.7	11	2.427	0	2	<5	<5	†
TB11	25	0	0.58	22	4.244	1	1	<5	5.7	†
LAG6	21	0	2.3	38	14.9	16	3	5.3	490	41.76

*Millerton Gulch sampling site was moved upstream during this water year to eliminate tidal influence.
MC1A refers to sampling site at Shoreline Hwy bridge, MC1 is upstream site.
† Censored data (<QL) handled by exclusion.

Table C18 – Summary of Trends Program Sediment Parameter Results for WY09

WY09 Sediment Lab Data										
	Turbidity (NTU)					Total Suspended Solids (TSS) (mg/L)				
Site Name	# of detections†	# samples <QL	Min.	Max.	Mean	# of detections†	# samples <QL	Min.	Max.	Mean
Lagunitas Creek										
SG1	20	10	0.25	24.4	2.991	1	12	<5	<10	†
LAGSPT	24	6	0.38	25.7	3.08	0	13	<5	<10	†
OLM11	26	4	<0.5	142	9.355	0	13	<5	<10	†
LAG1	22	7	0.43	28.5	3.482	3	10	<5	<10	†
West Shore										
FV1	28	2	<0.5	8.95	1.958	0	13	<5	<10	†
WG1	7	1	<0.5	295	45.81	0	4	<5	<5	†
East Shore										
MC1	11	6	0.18	33.6	4.832	0	5	<5	<10	†
MP36.17	30	0	0.75	35.1	4.688	0	13	<5	<10	†
Walker Creek										
WKR2	30	0	0.87	267	17.74	0	13	<5	<10	†
WKR1	29	0	1.5	96.9	8.035	8	5	<5	22	10.68
KYS1	14	0	2.07	66.7	11.9	0	7	<5	<10	†
Tomales Bay Sites										
TB2	12	0	0.74	3.35	1.594	0	1	<5	<5	†
TB4	12	0	0.53	3.17	1.37	0	1	<5	<5	†
TB11	17	0	0.53	13.5	3.096	0	4	<5	<5	†
LAG6	24	0	0.8	30.8	8.74	9	0	9.7	43	18.3

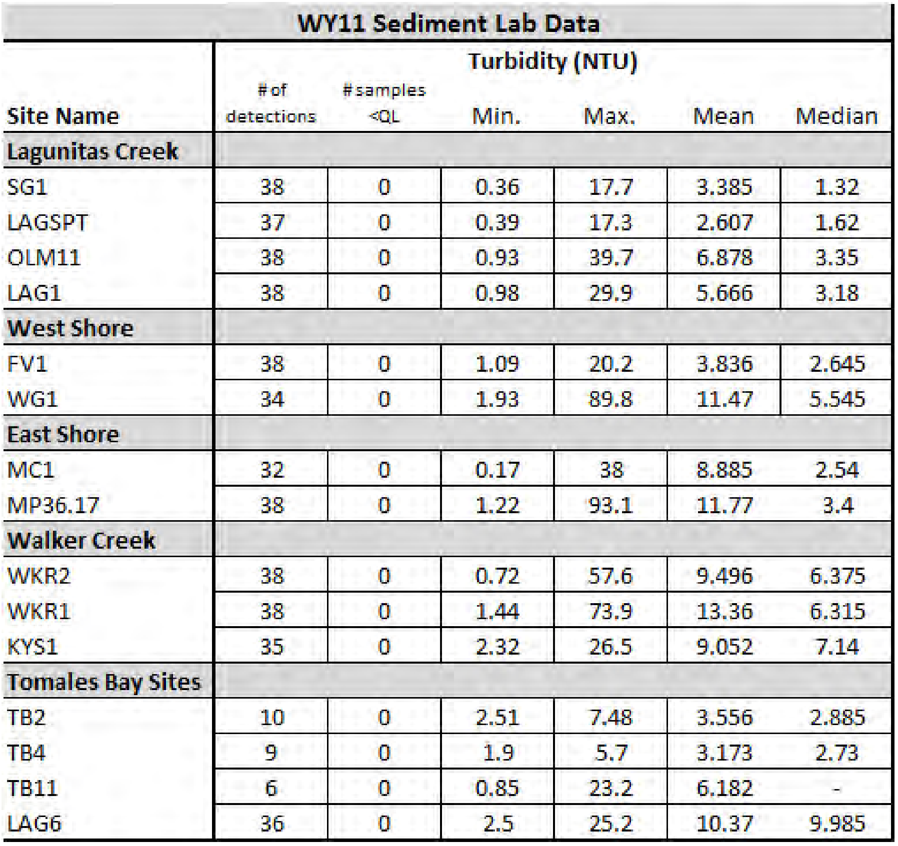
† Censored data (<QL) handled by exclusion.

Table C19 – Summary of Trends Program Sediment Parameter Results for WY10

WY10 Sediment Lab Data											
	Turbidity (NTU)						Total Suspended Solids (TSS) (mg/L)				
Site Name	# of detections†	# samples <QL	Min.	Max.	Mean	Median	# of detections†	# samples <QL	Min.	Max.	Mean
Lagunitas Creek											
SG1	41	0	0.38	241	16.19	1.53	2	0	10	230	120
LAGSPT	41	0	0.5	249	11.64	1.5	2	0	10	250	130
OLM11	41	0	0.69	347	26.17	3.01	2	0	73	360	216.5
LAG1	41	0	0.68	899	30.93	2.47	2	0	22	370	196
West Shore											
FV1	41	0	0.79	223	9.885	2.53	2	0	7.2	50	28.6
WG1	28	0	0.86	28.8	6.667	3.235	1	1	8.2	8.2	8.2
East Shore											
MC1	35	0	0.15	161	18.66	3.28	2	0	25	130	77.5
MP36.17	41	0	1.14	113	14.58	3.98	2	0	21	63	42
Walker Creek											
WKR2	39	0	0.77	>1000	14.6	3.51	2	0	120	1200	660
WKR1	41	0	1.37	315	26.58	5.43	2	0	140	360	250
KYS1	36	0	1.8	111	13.01	5.91	2	0	15	79	47
Tomales Bay Sites											
TB2	9	0	0.88	3.79	2.343	2.23	*	*	*	*	*
TB4	9	0	1.88	5.82	3.27	3.09	*	*	*	*	*
TB11	9	0	0.76	28	6.786	2.36	*	*	*	*	*
LAG6	40	0	2.4	47.1	12.78	10.02	1	0	23	23	23

† Censored data (<QL) handled by exclusion.

Table C20 – Summary of Trends Program Sediment Parameter Results for WY11



WY11 Sediment Lab Data						
	Turbidity (NTU)					
Site Name	# of detections	# samples <QL	Min.	Max.	Mean	Median
Lagunitas Creek						
SG1	38	0	0.36	17.7	3.385	1.32
LAGSPT	37	0	0.39	17.3	2.607	1.62
OLM11	38	0	0.93	39.7	6.878	3.35
LAG1	38	0	0.98	29.9	5.666	3.18
West Shore						
FV1	38	0	1.09	20.2	3.836	2.645
WG1	34	0	1.93	89.8	11.47	5.545
East Shore						
MC1	32	0	0.17	38	8.885	2.54
MP36.17	38	0	1.22	93.1	11.77	3.4
Walker Creek						
WKR2	38	0	0.72	57.6	9.496	6.375
WKR1	38	0	1.44	73.9	13.36	6.315
KYS1	35	0	2.32	26.5	9.052	7.14
Tomales Bay Sites						
TB2	10	0	2.51	7.48	3.556	2.885
TB4	9	0	1.9	5.7	3.173	2.73
TB11	6	0	0.85	23.2	6.182	-
LAG6	36	0	2.5	25.2	10.37	9.985

Appendix D -
WY08- WY12-Additional Trends Program Water Quality Graphs

This appendix contains additional figures presenting the data from the TBWC's Water Quality Monitoring Program discussed in the main body of this Final Technical Report. Many of the graphs in this appendix mirror the boxplot and time-series figures in the main body of the TBWC WY12 Annual WQ Report, but include outlier results. Some of the graphs in the main body of the report do not include outlier results because their inclusion serves to obscure the relative median, ranges or resolution of each site's parameter results. The graphs in this appendix are meant to supplement those in the main report by providing visual representation of the full range of results, particularly those at the extreme ends of the result range.

Additionally, in the second section of this appendix, we have included time-series graphs of each lab parameter by water year for each site, presented by week for each of the five monitoring years. These graphs allow a within-site comparison of nutrient, sediment and bacteria across water years and are a useful visual representation of the annual patterns of pollutant levels by site, across the Tomales Bay watershed. Comparing the graphs from different sites for each parameter provides evidence of the different watershed responses (i.e. the timing and magnitude of pollutant concentrations peaks across each site).

List of Figures:

Section I

Figures in Section II – Site-Specific Graphs by Water Year Week for Lab Parameters

A. Nitrate Results

B. Total Kjeldahl Nitrogen Results

Section I – Additional Graphs Showing Outliers & Data Omitted From Main Body Figures

Figure D1 – East & West Shore Tributaries TKN by Water Year (No Omits)

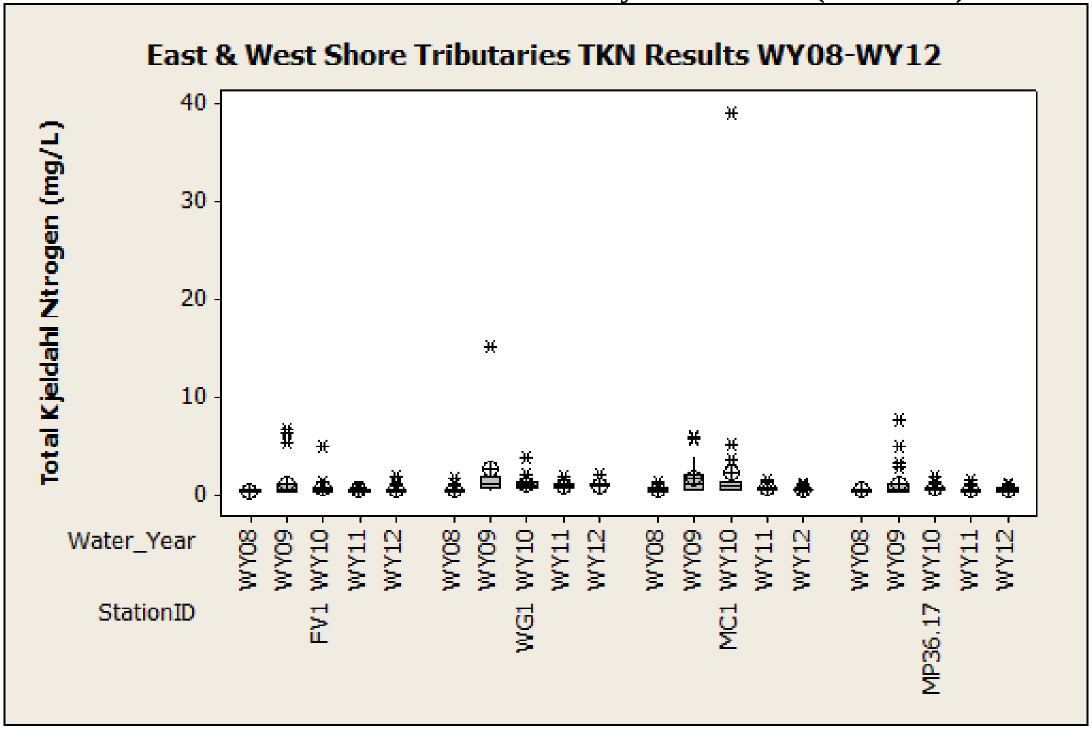


Figure D2 – East & West Shore Tributaries TKN Time Series WY08-WY12 (No Omits)

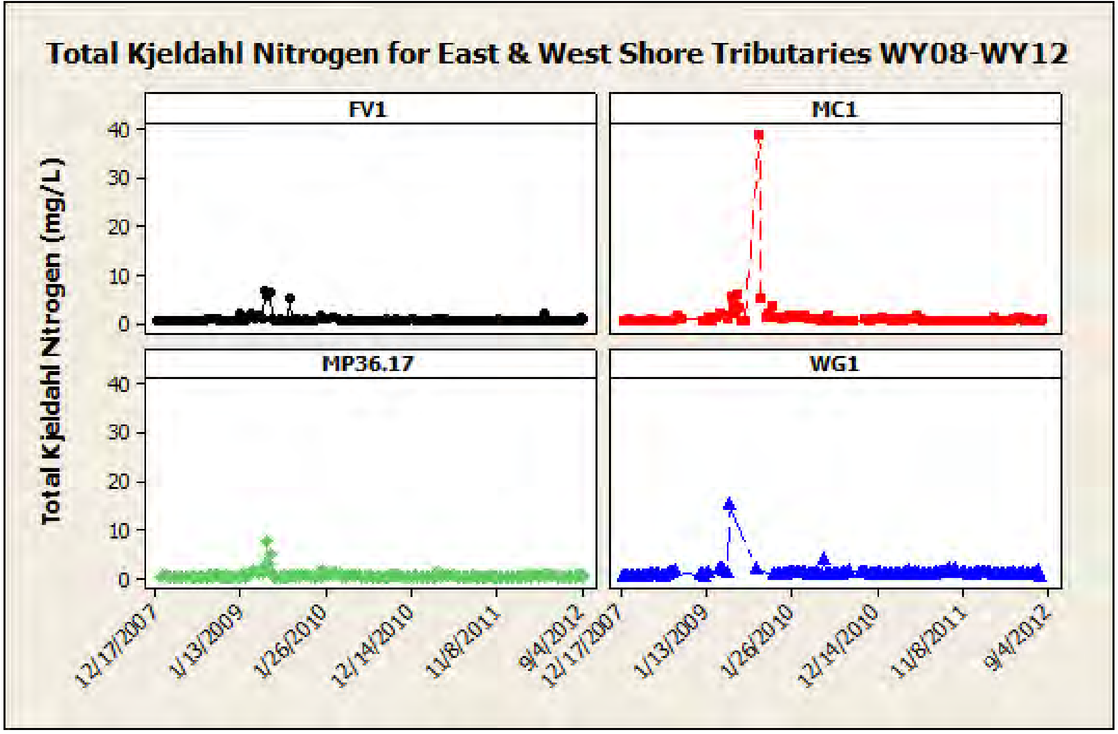


Figure D3– Lagunitas Creek Watershed Turbidity by Water Year (No Omits)

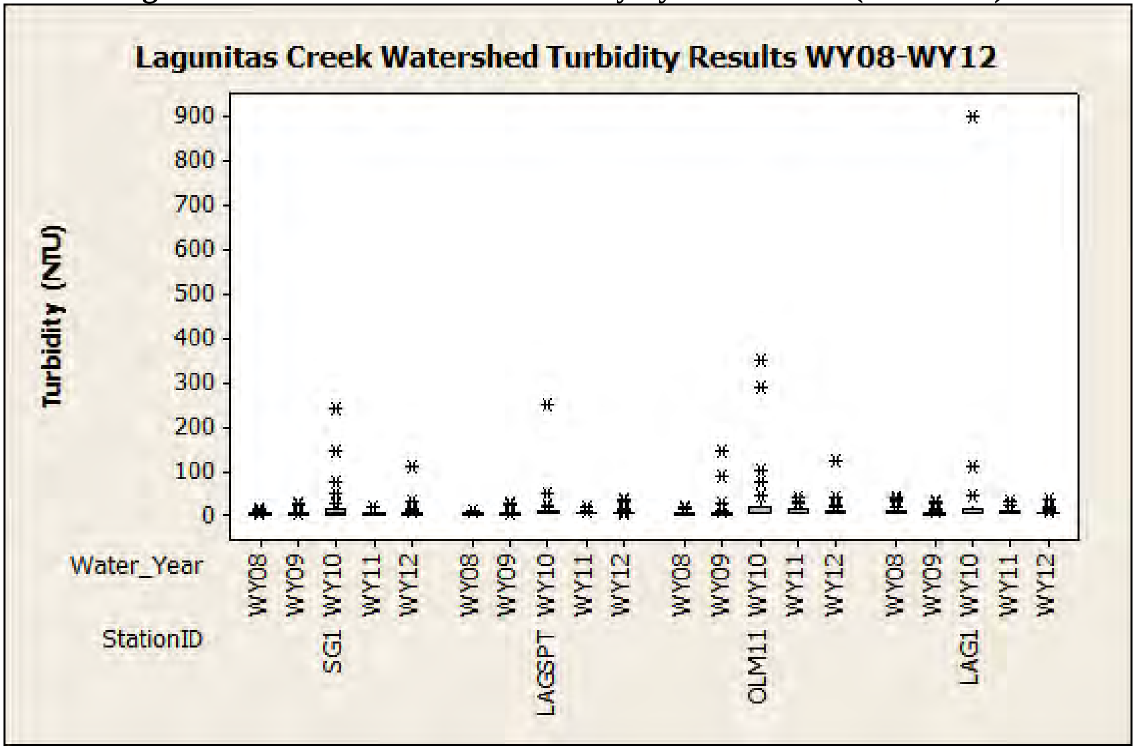


Figure D4 – East & West Shore Tributaries Turbidity by Water Year (No Omits)

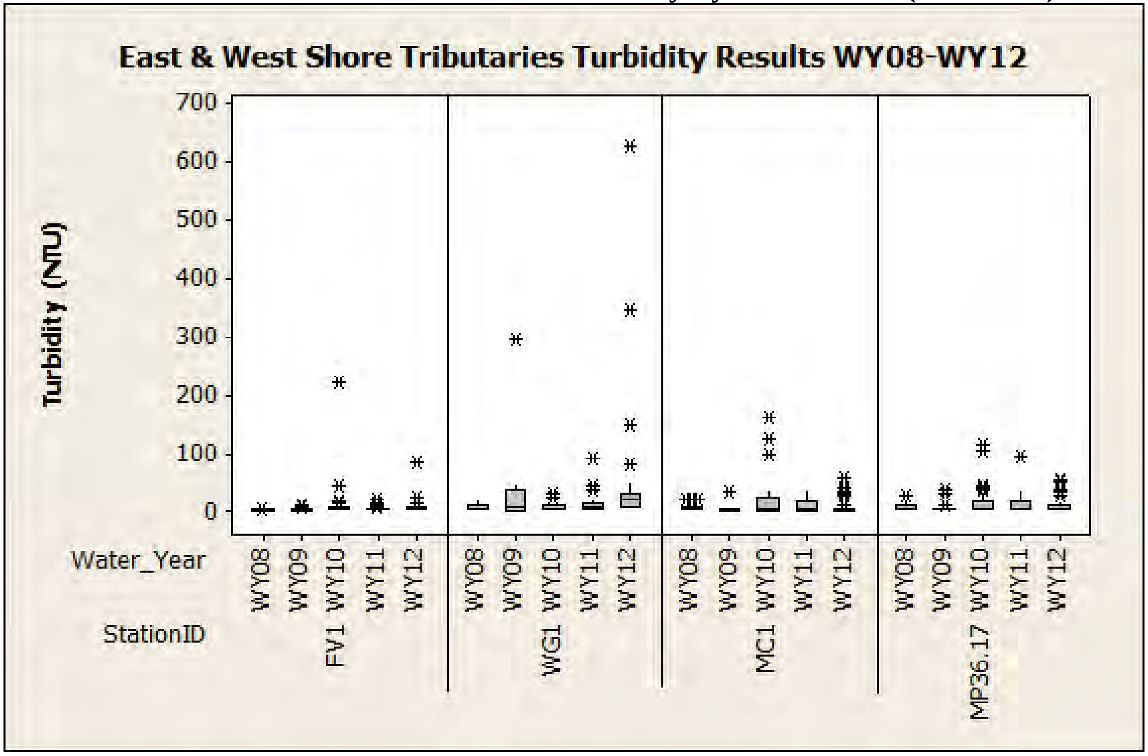


Figure D5 – East & West Shore Tributaries Turbidity Timeseries (No Omits)

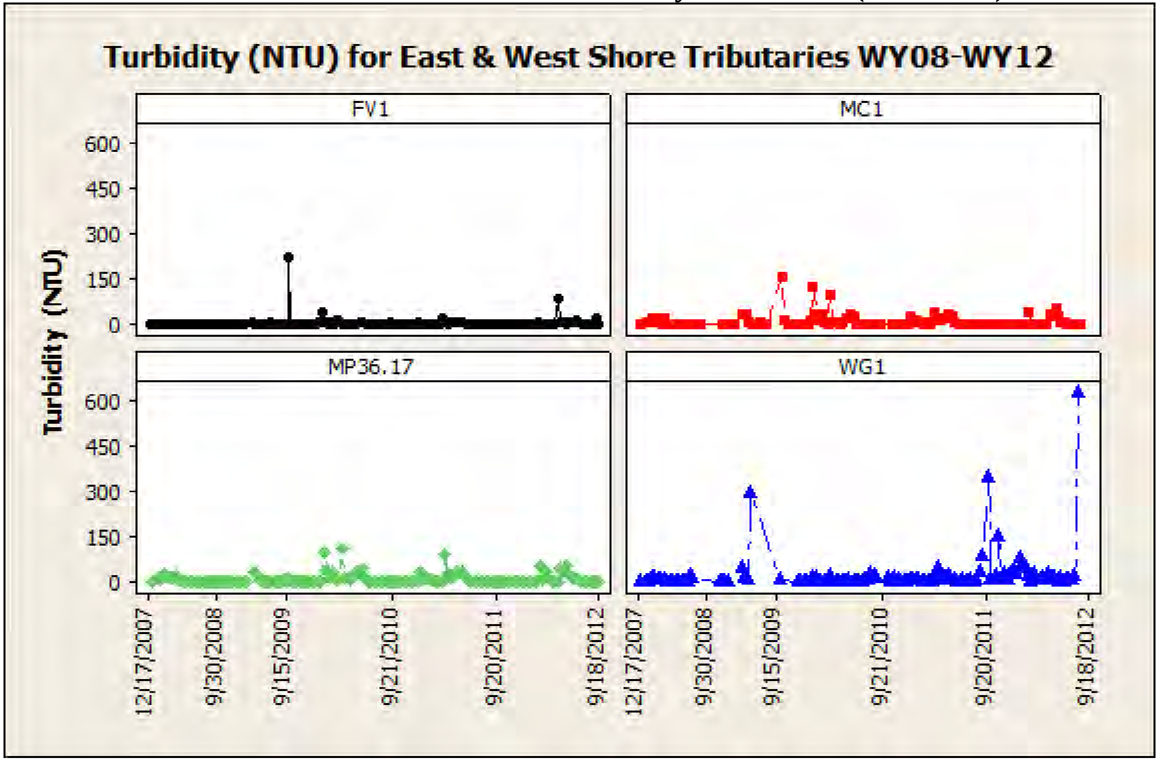


Figure D6– Walker Creek Watershed Turbidity by Water Year (No Omits)

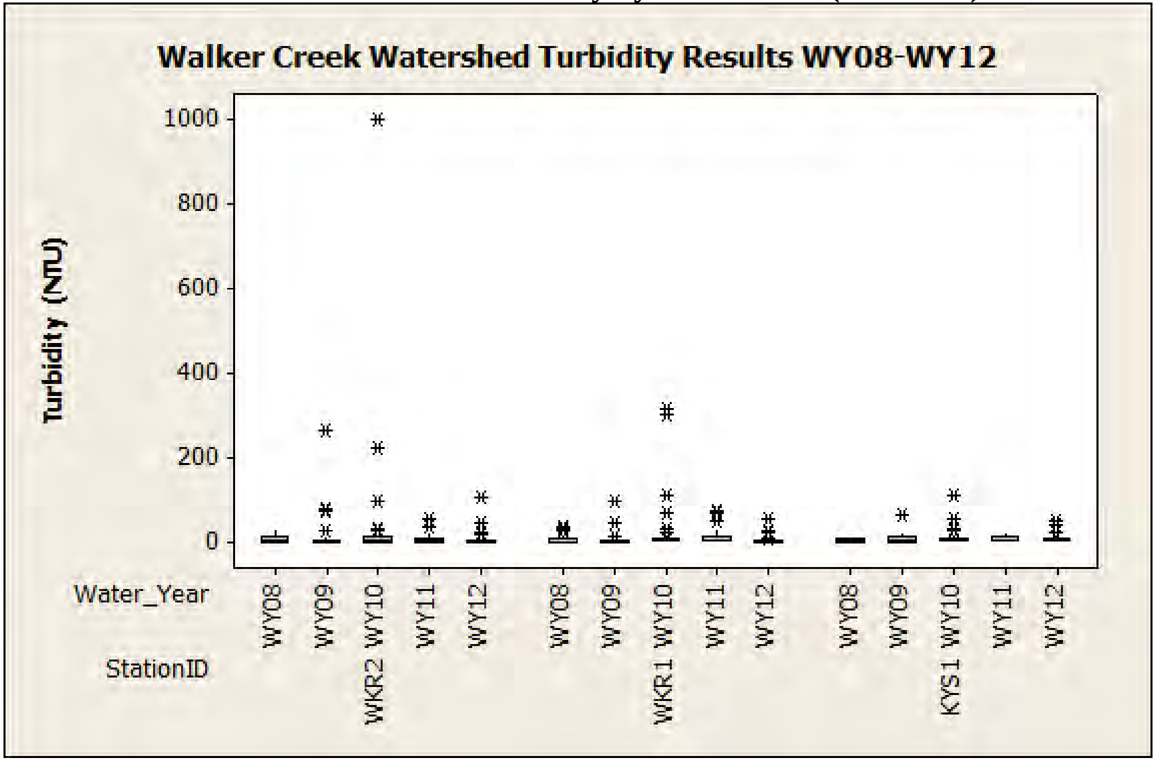


Figure D7 – Walker Creek Turbidity Time Series (No Omits)

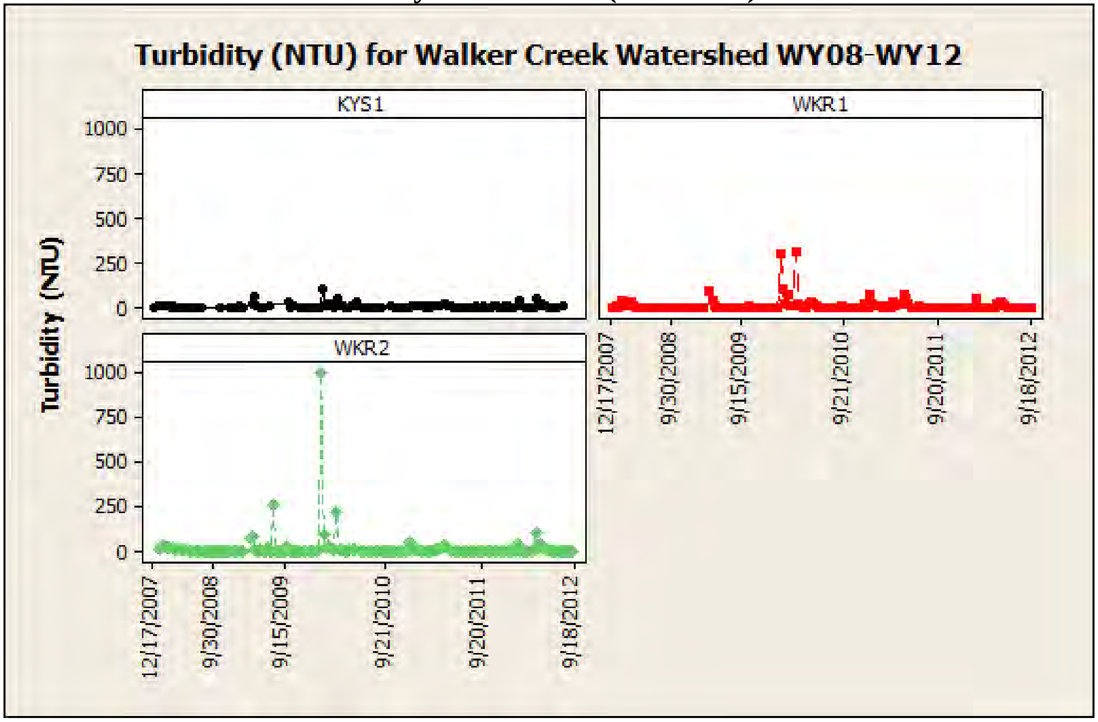


Figure D8 – Lagunitas Creek Watershed Fecal Coliform by Water Year (No Omits)

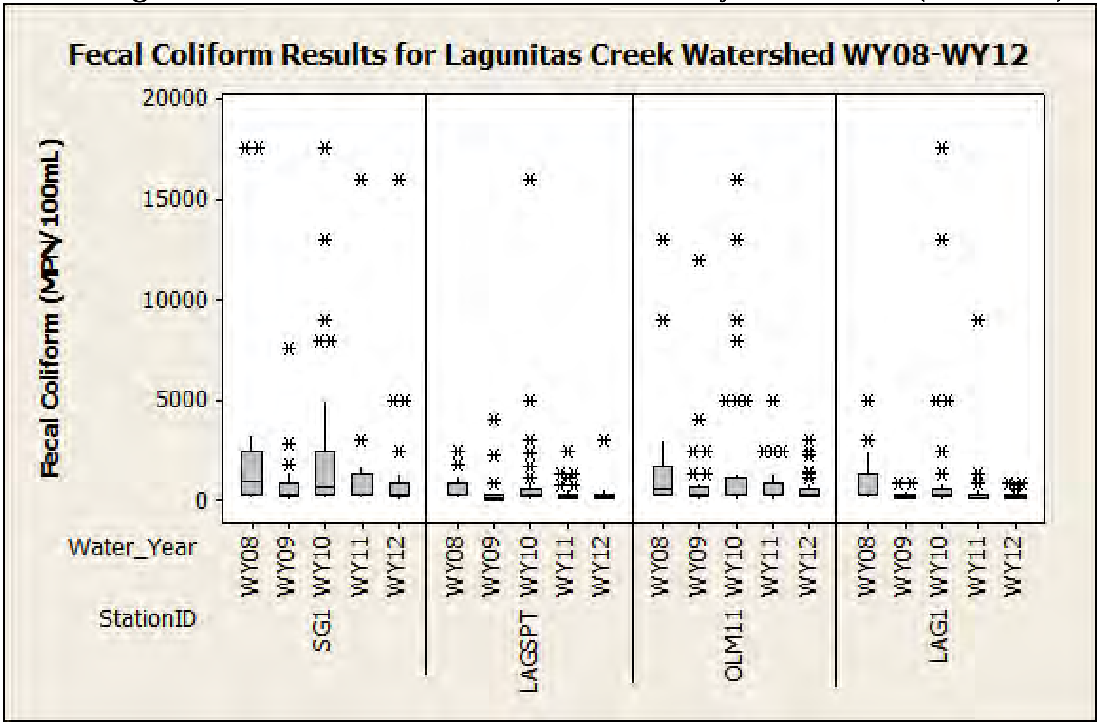


Figure D9 – Lagunitas Creek Watershed log Fecal Coliform by Water Year (No Omits)

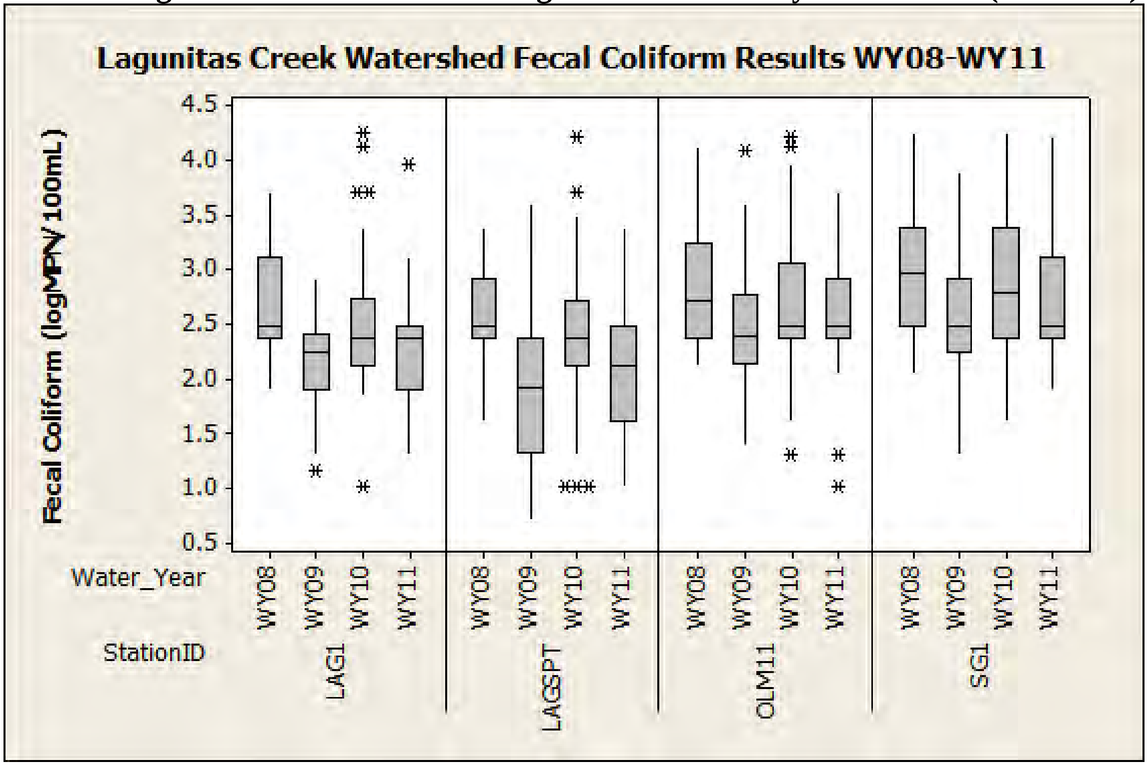


Figure D10 – East & West Shore Tributaries Fecal Coliform by Water Year (No Omits)

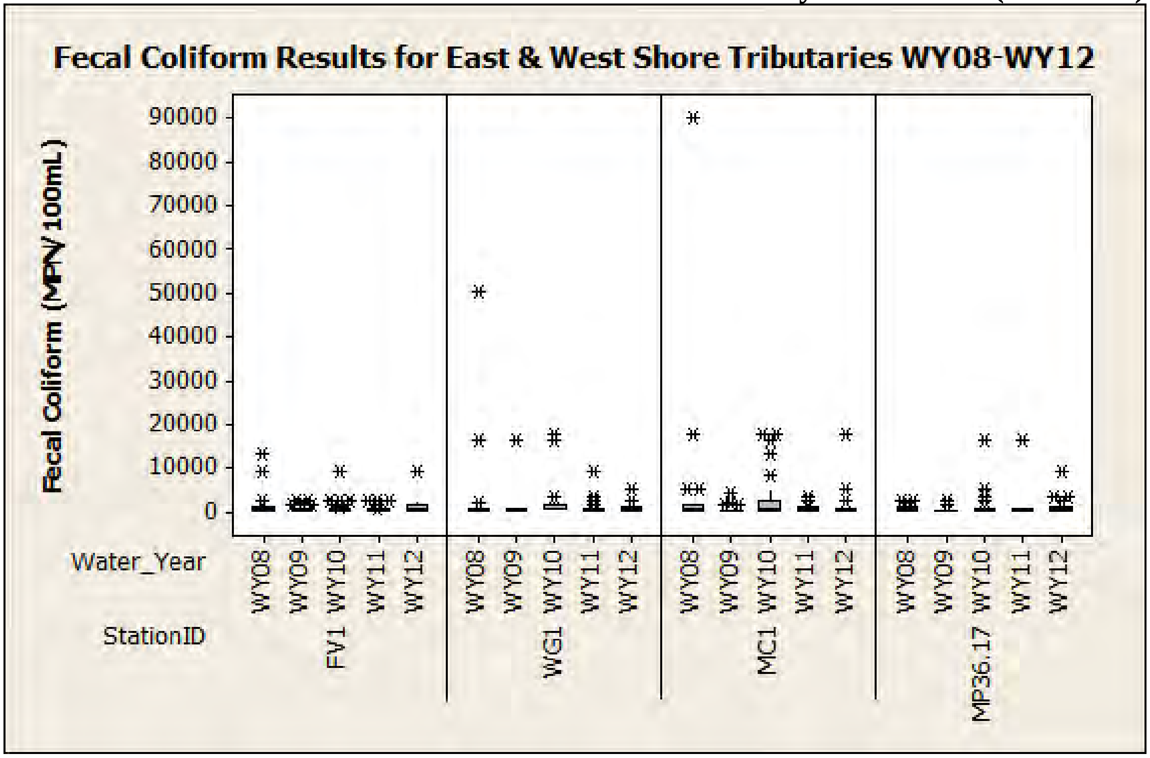


Figure D11 – East & West Shore Tributaries log Fecal Coliform by Water Year

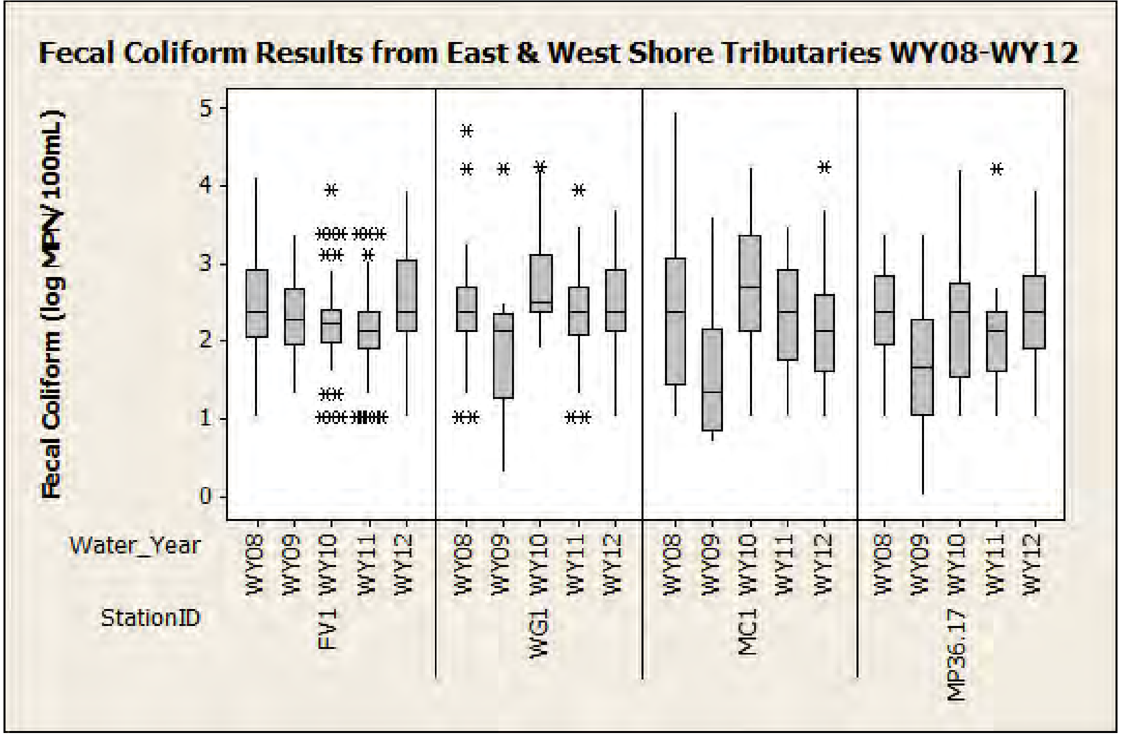


Figure D12 – Walker Creek Watershed Fecal Coliform by Water Year (One Omit)

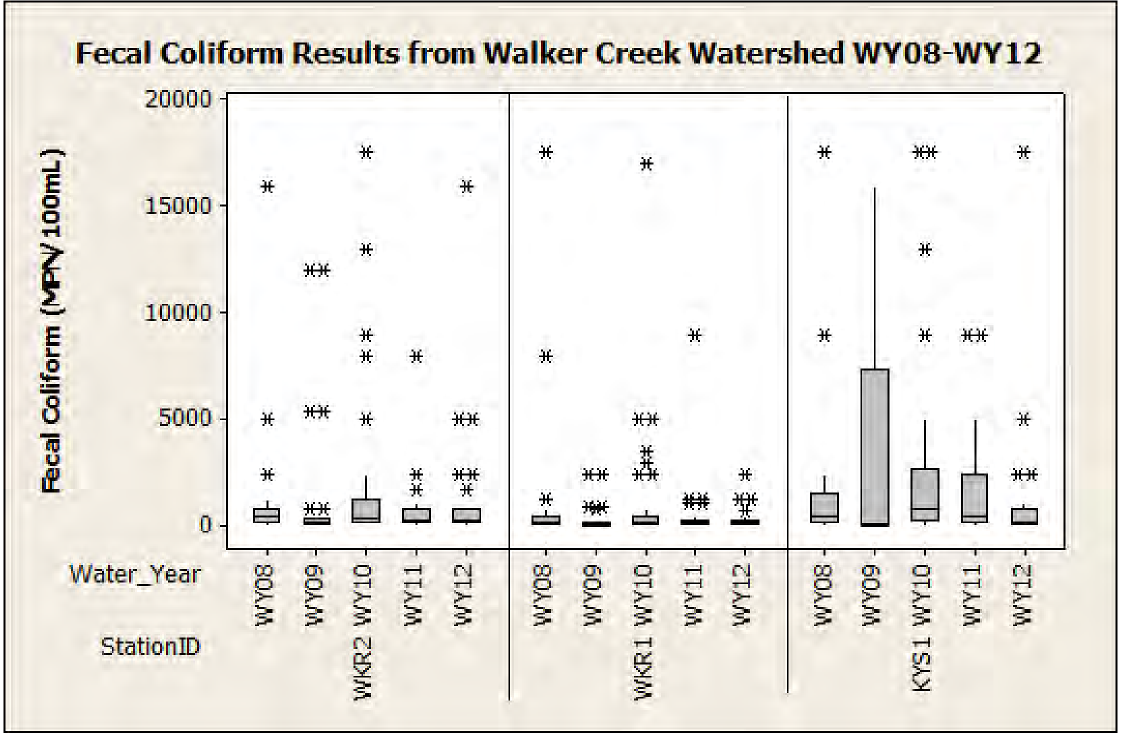


Figure D13 – Walker Creek Watershed log Fecal Coliform by Water Year

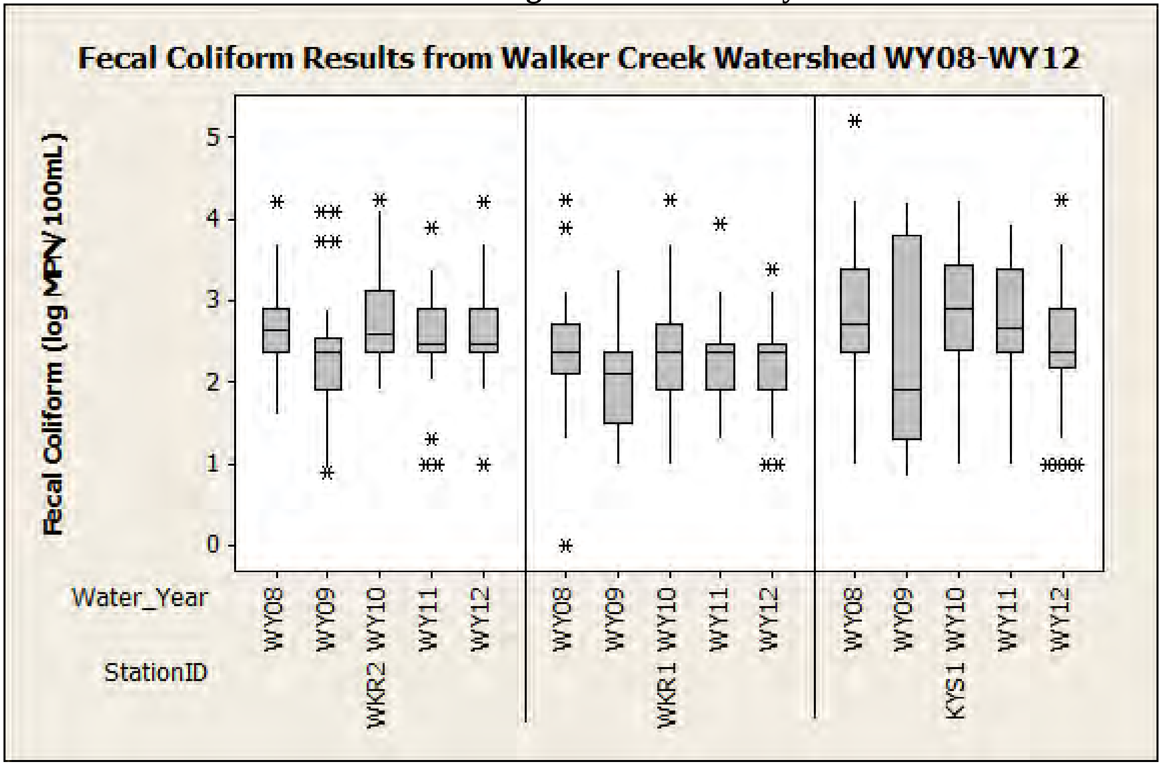


Figure D14 – Tomales Bay Sites Fecal Coliform by Water Year (No Omits)

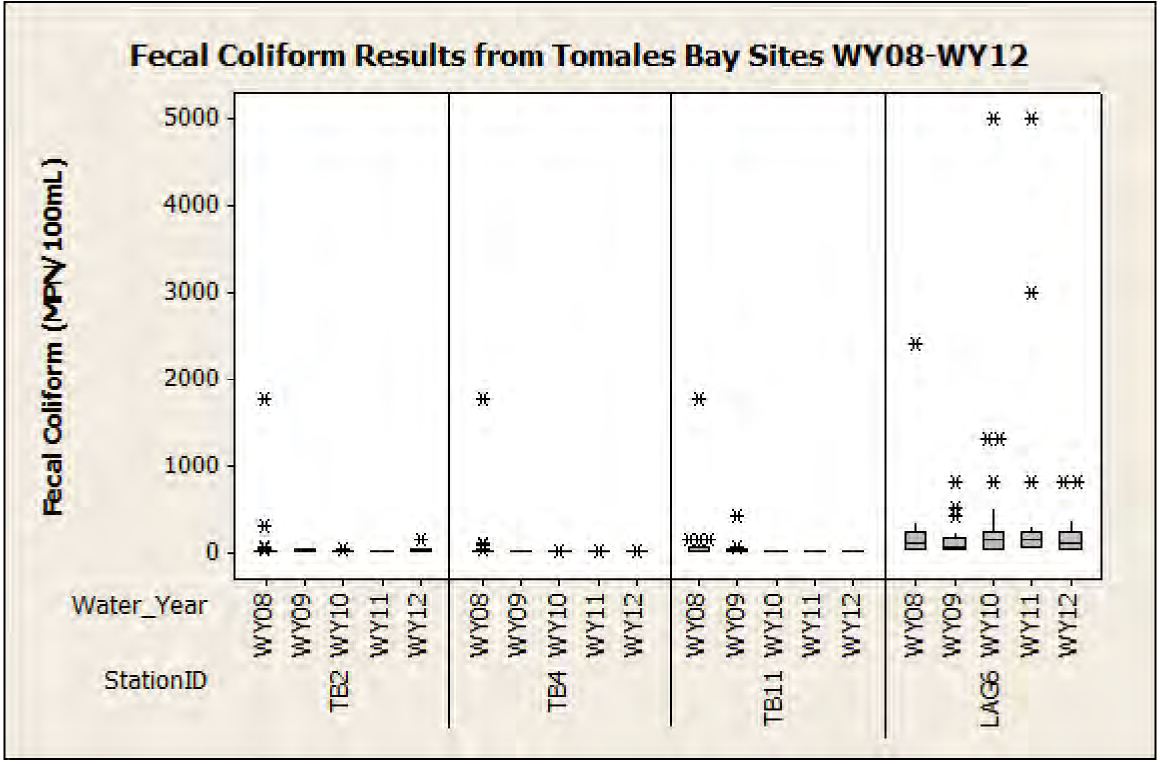
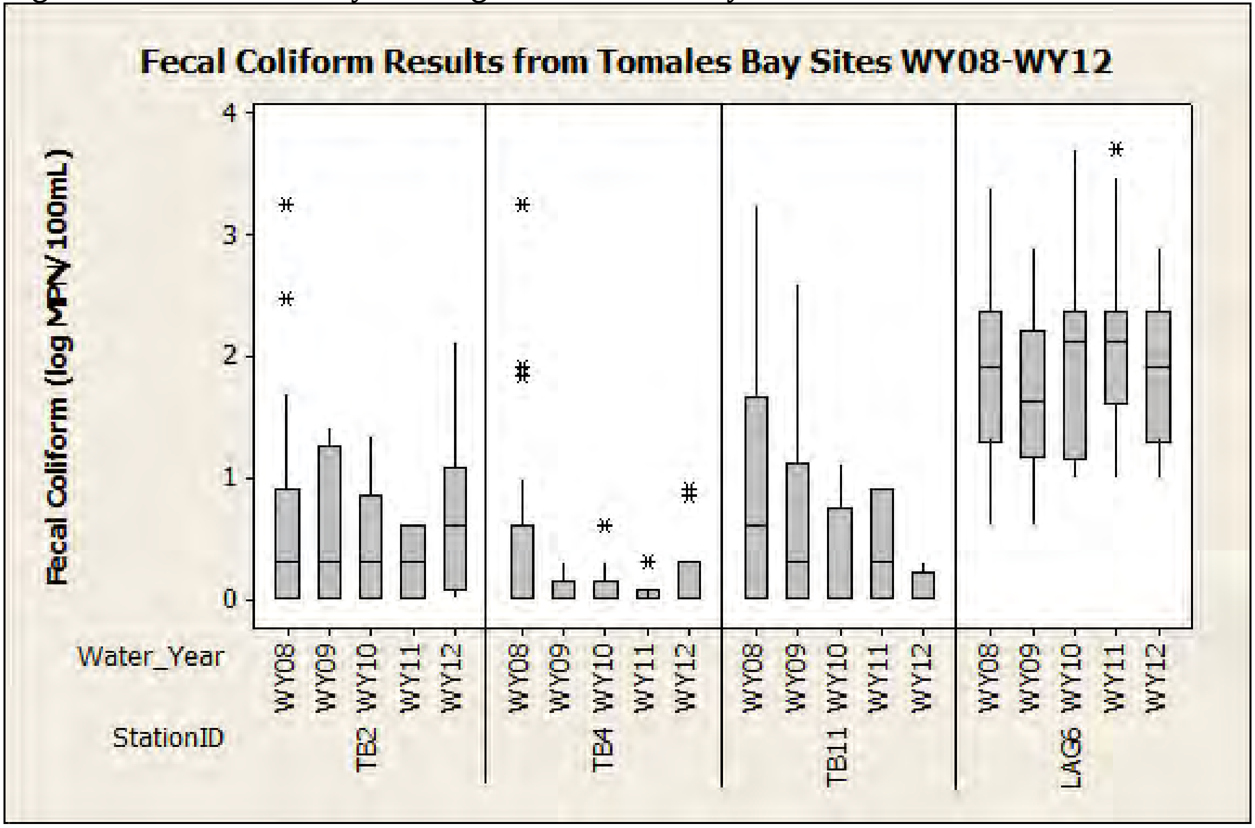


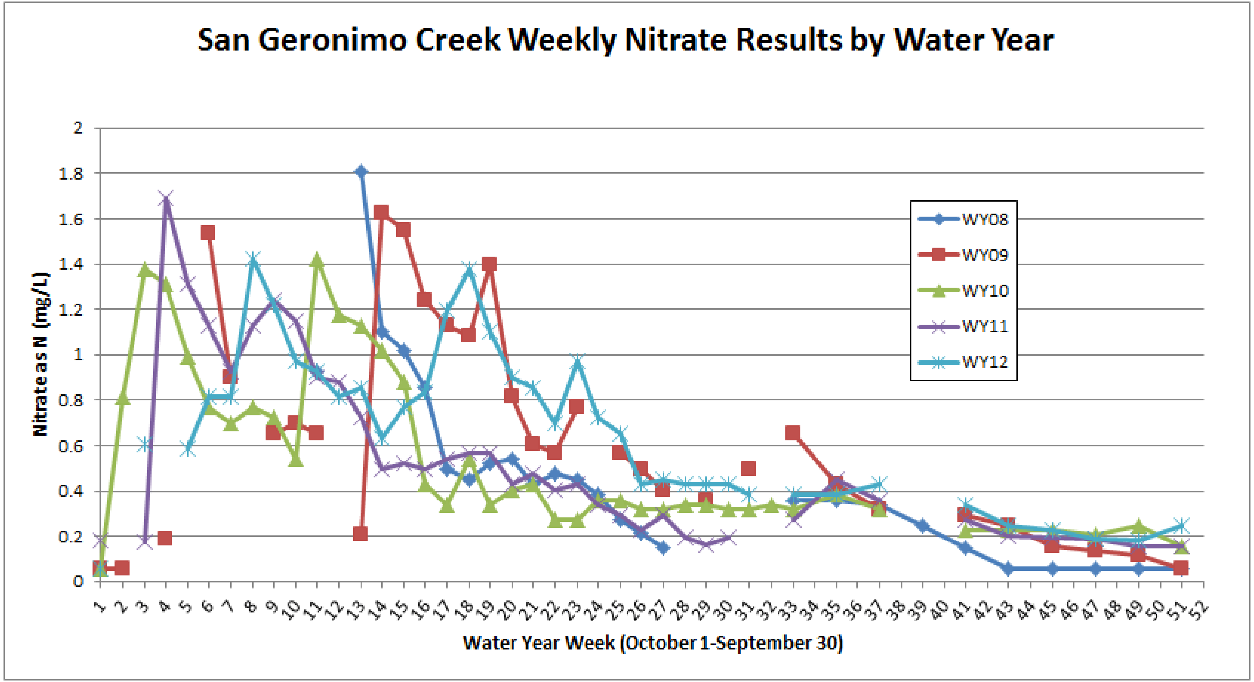
Figure D15 – Tomales Bay Sites log Fecal Coliform by Water Year

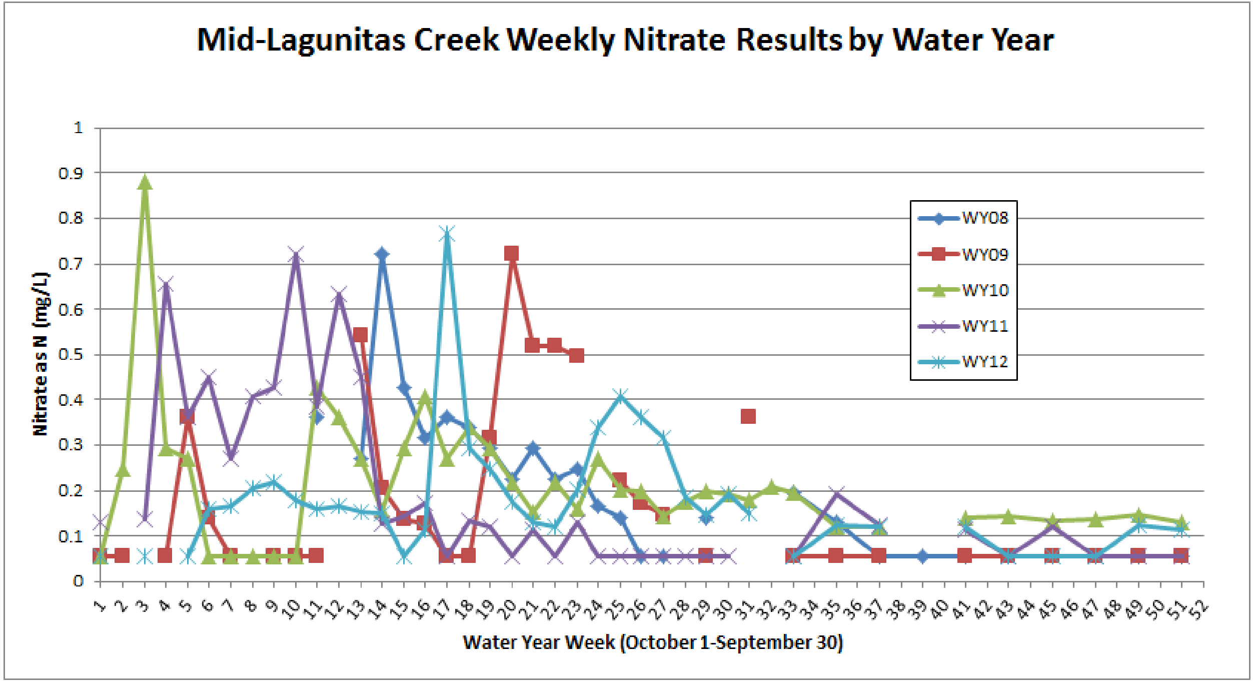


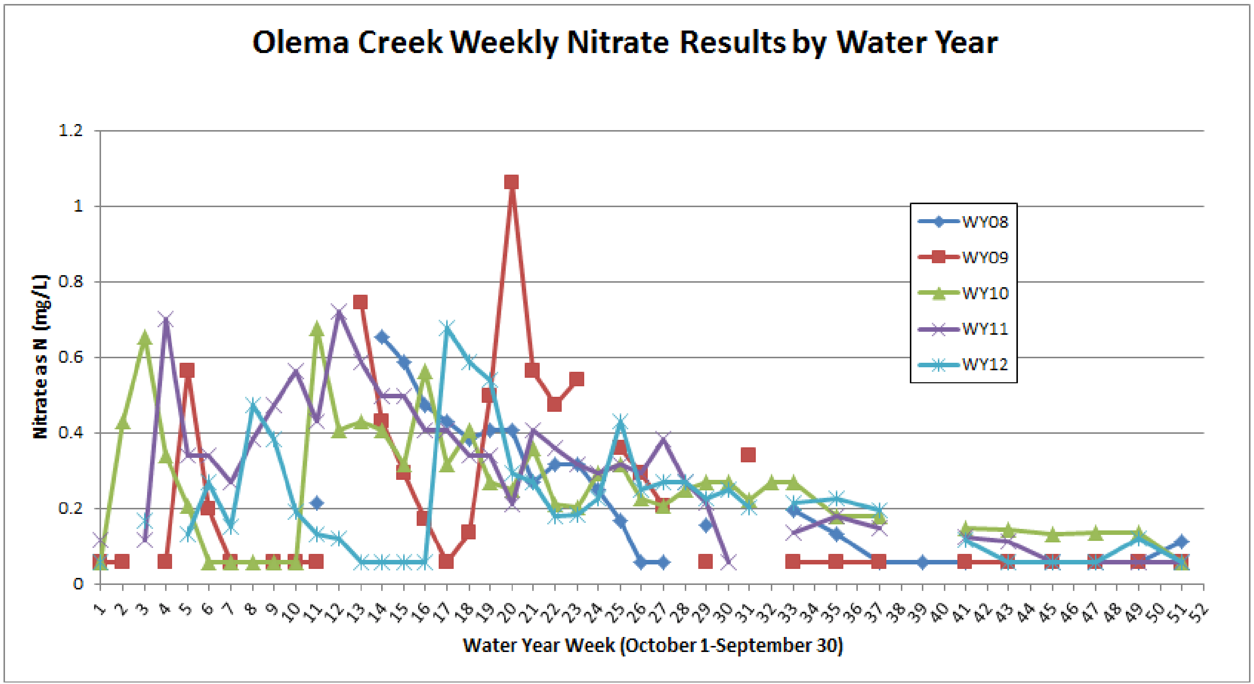
Section II – Site-Specific Graphs by Water Year Week for Lab Parameters

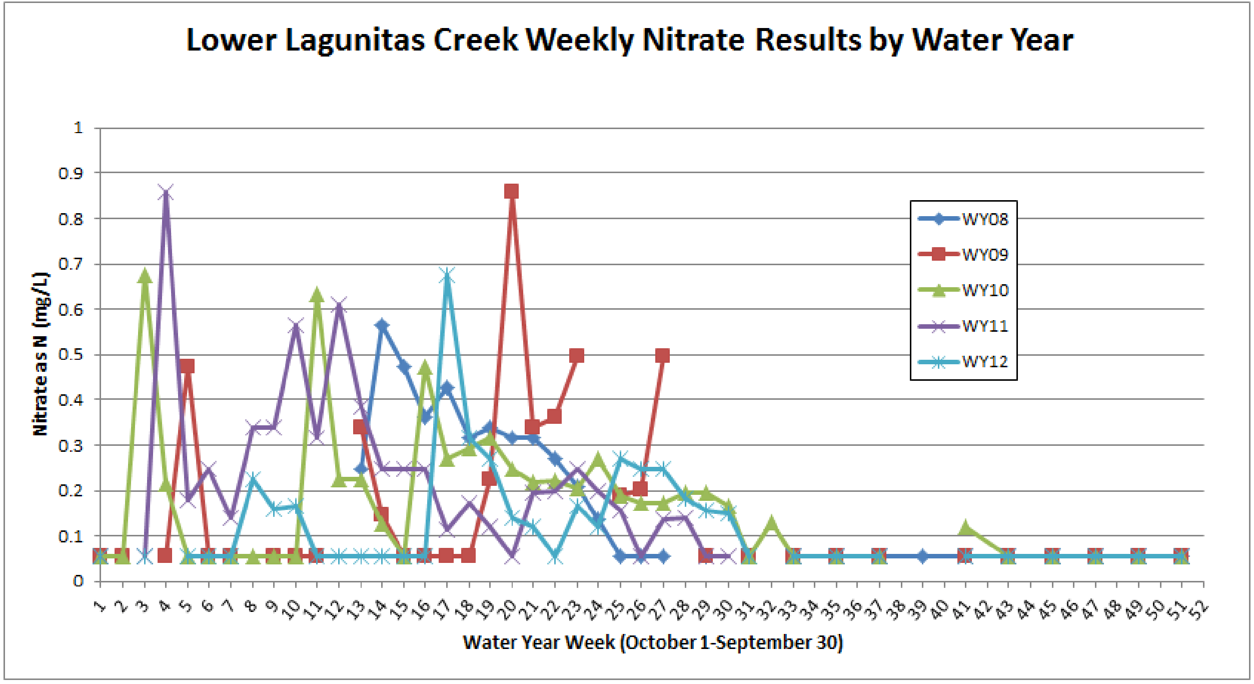
A. Nitrate Results

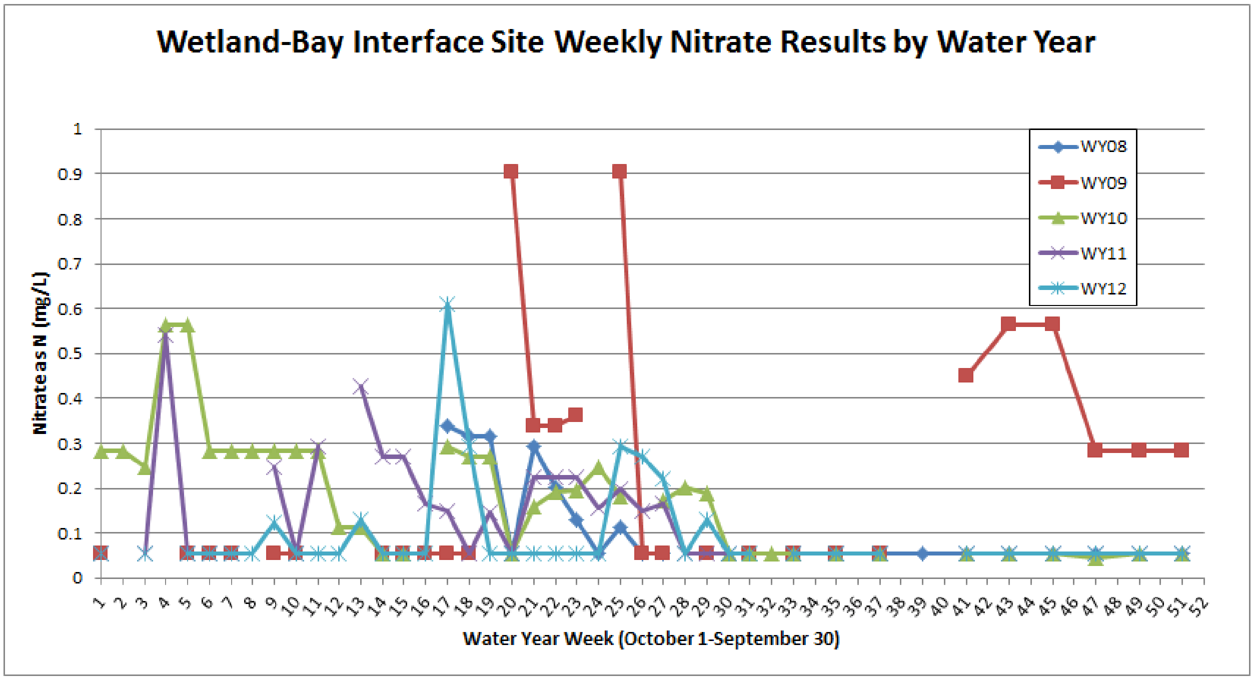
i. Lagunitas Creek watershed sites



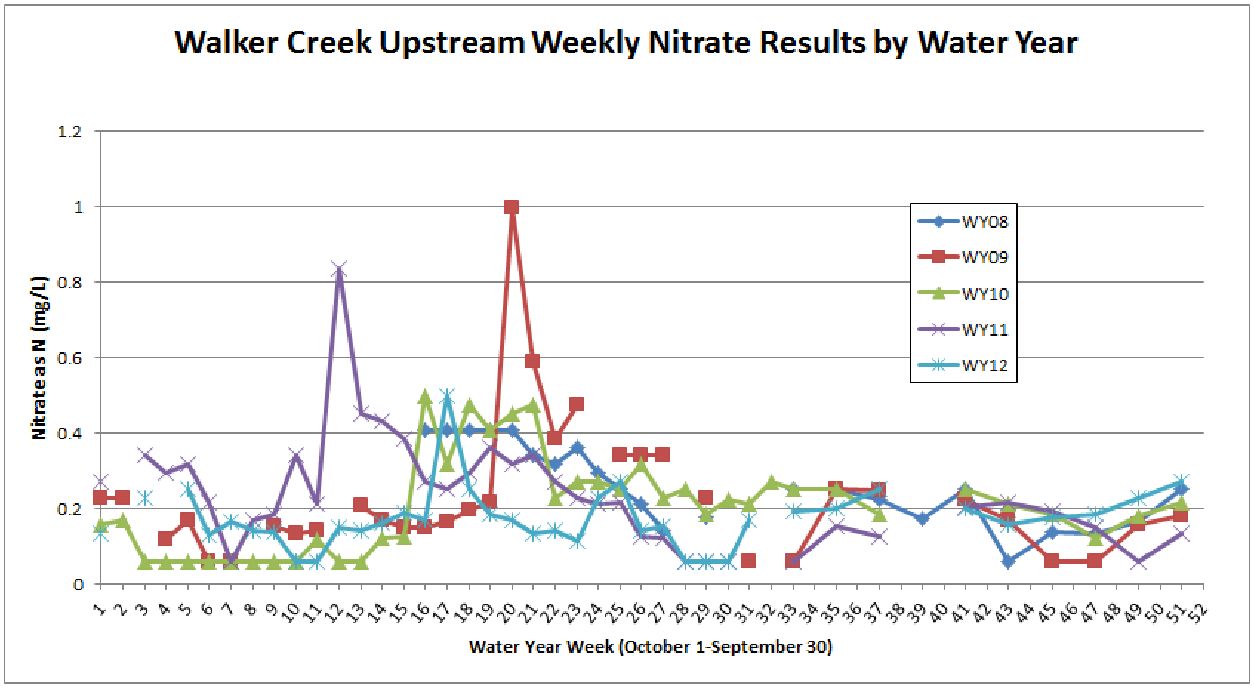


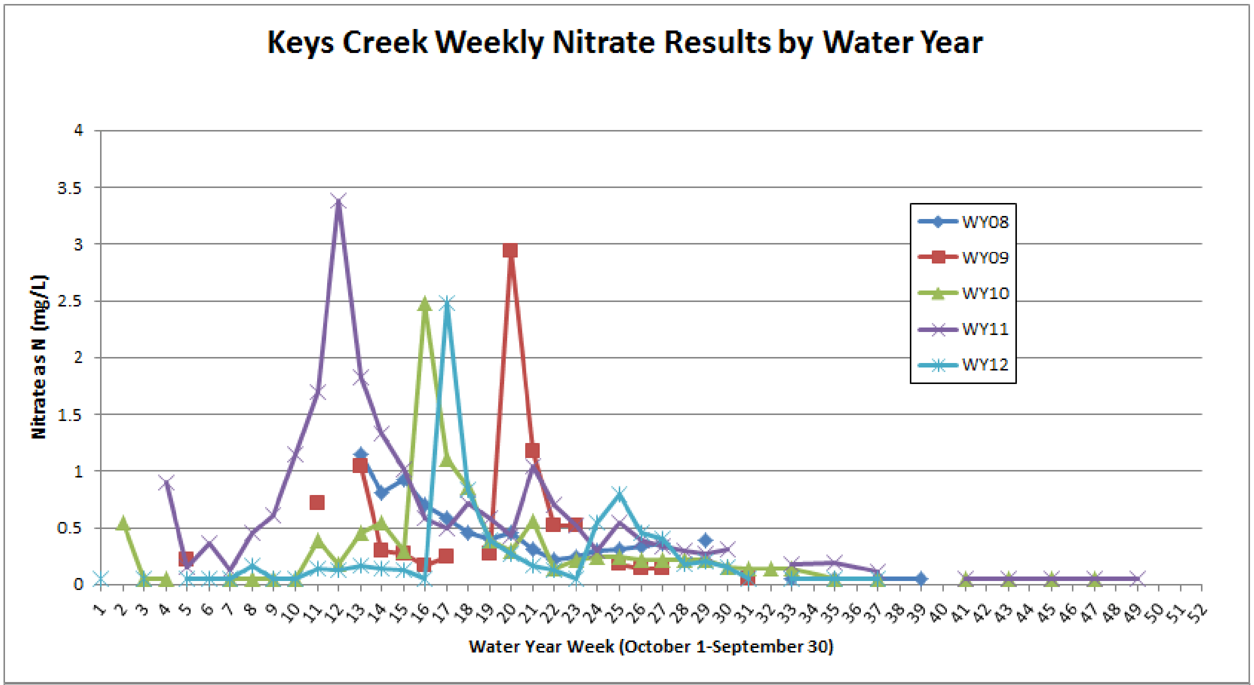

Olema Creek Weekly Nitrate Results by Water Year
Nitrate as N (mg/L)
1.2
1
0.8
0.6
0.4
0.2
0
Water Year Week (October 1-September 30)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
WY08
WY09
WY10
WY11
WY12


Lower Lagunitas Creek Weekly Nitrate Results by Water Year
Nitrate as N (mg/L)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Water Year Week (October 1-September 30)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
WY08
WY09
WY10
WY11
WY12

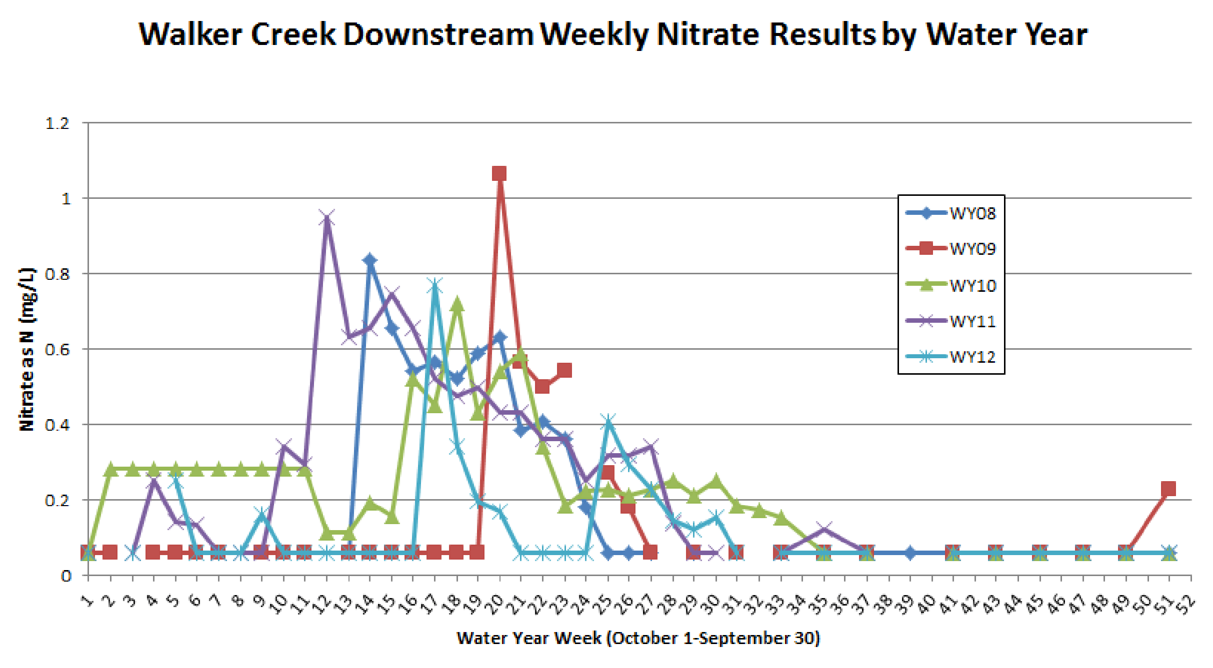


ii. Walker Creek watershed sites



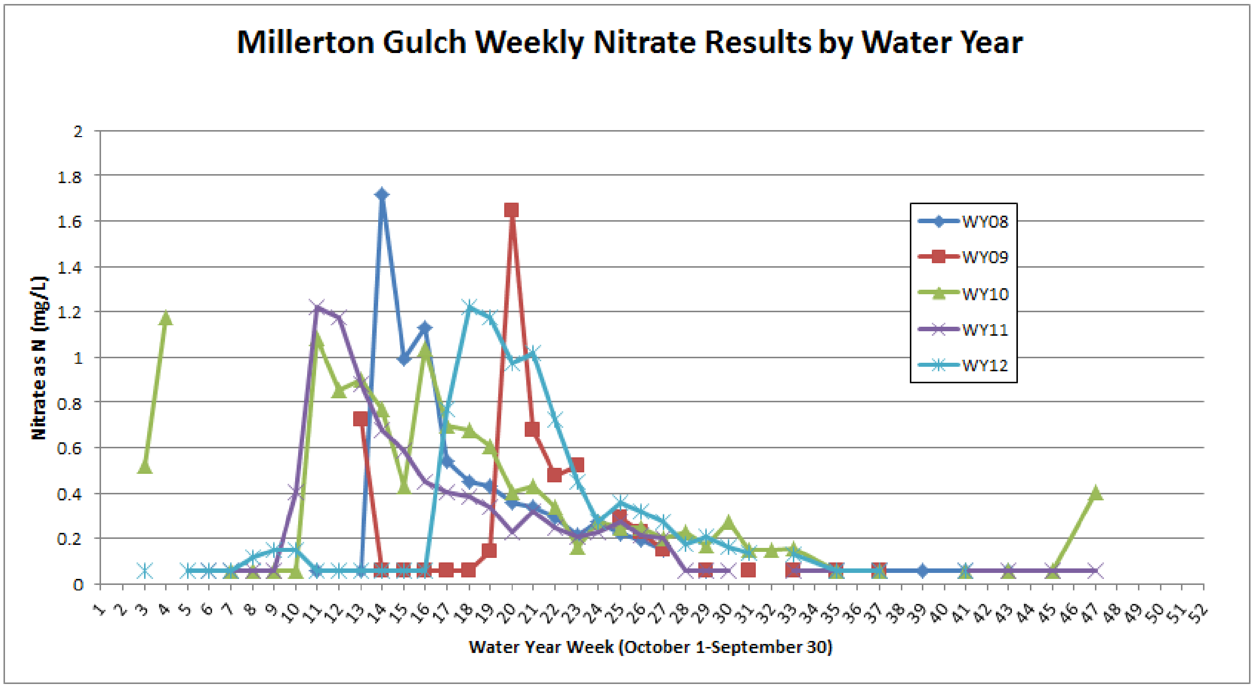


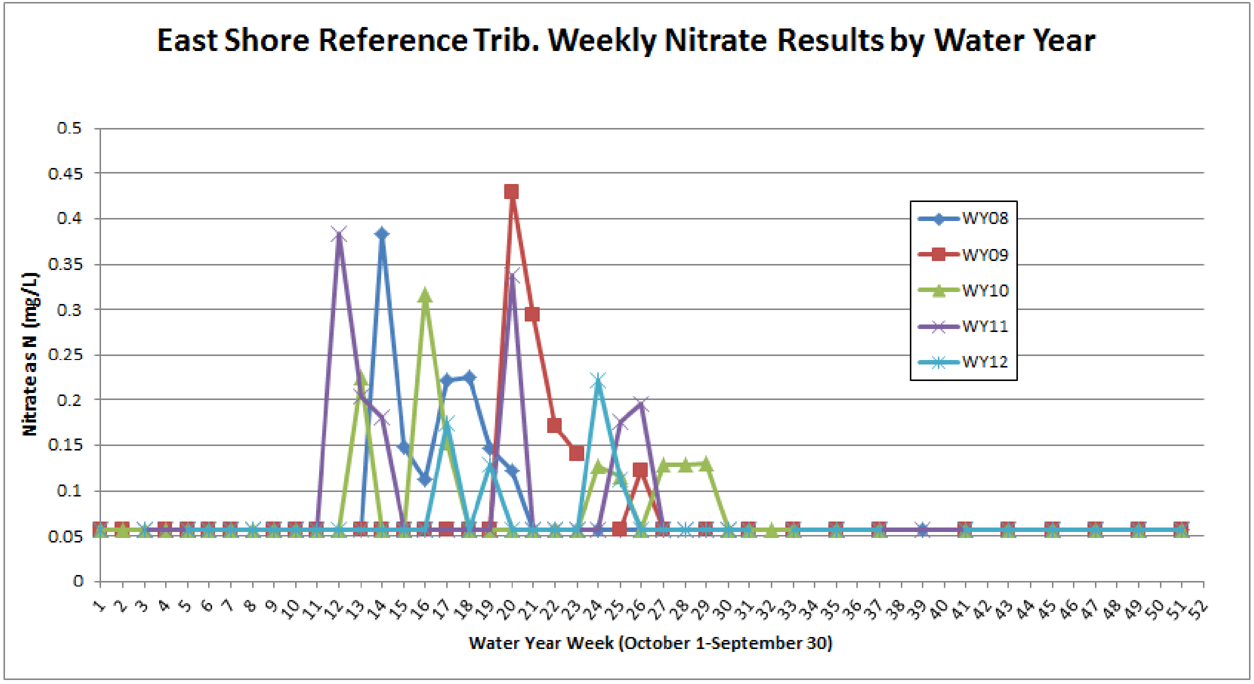
Keys Creek Weekly Nitrate Results by Water Year

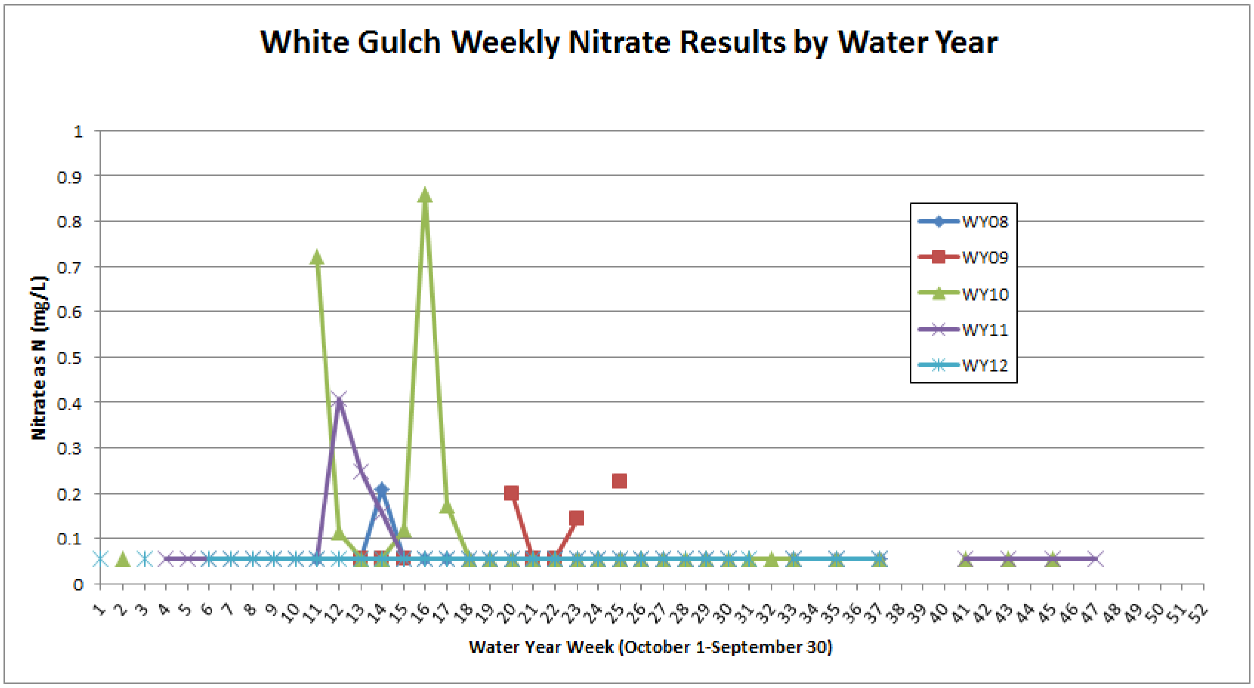


Walker Creek Downstream Weekly Nitrate Results by Water Year

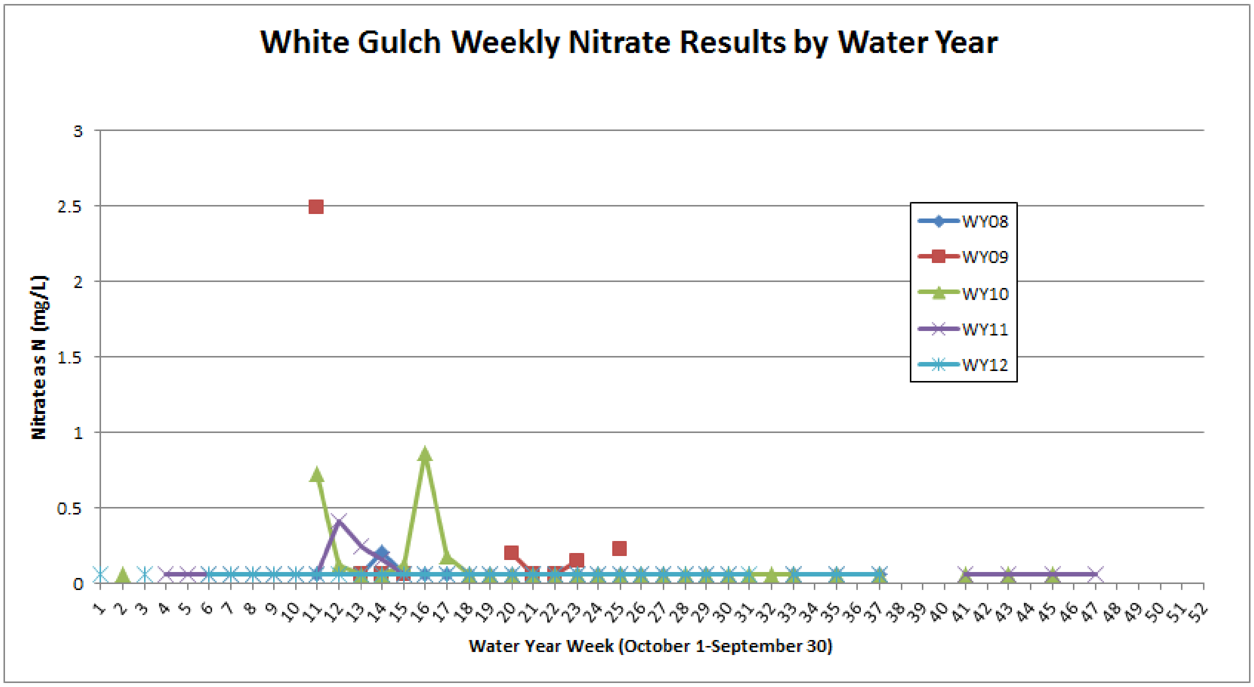
iii. Coastal Tributaries Watershed Sites

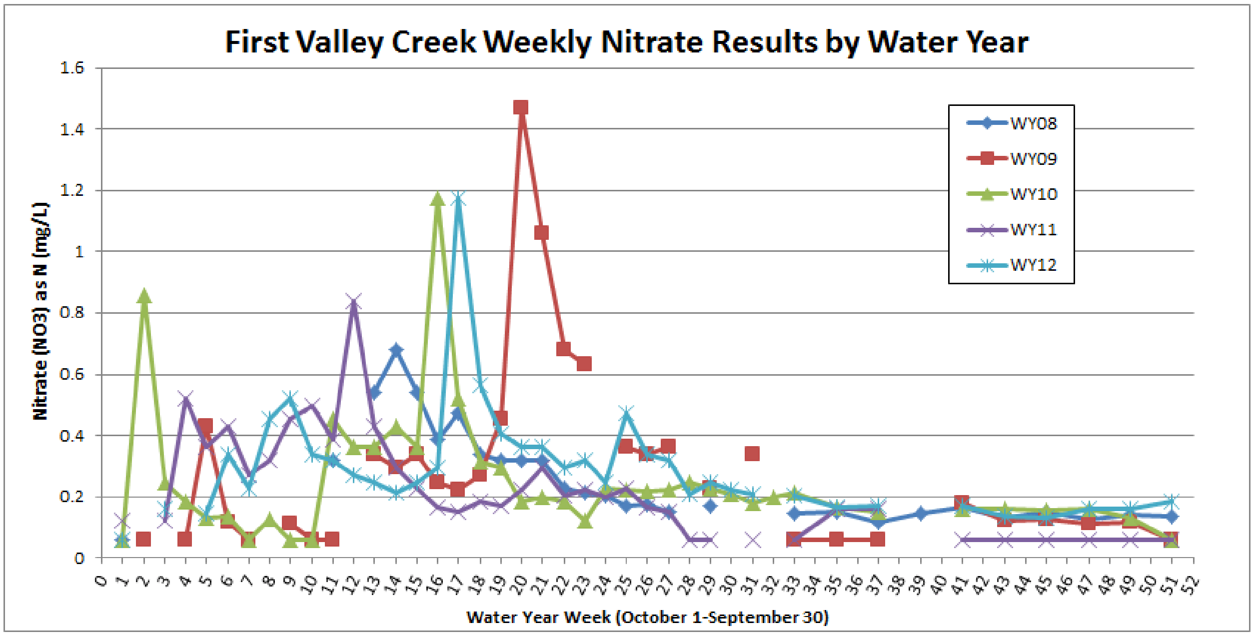




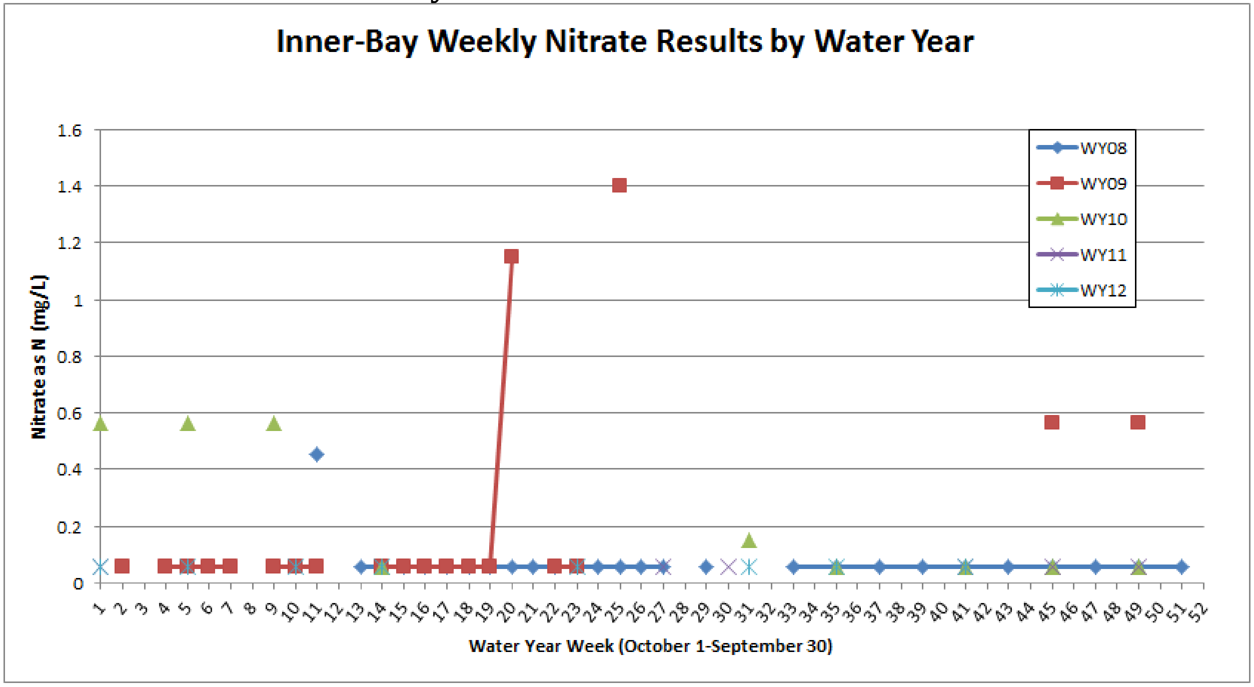


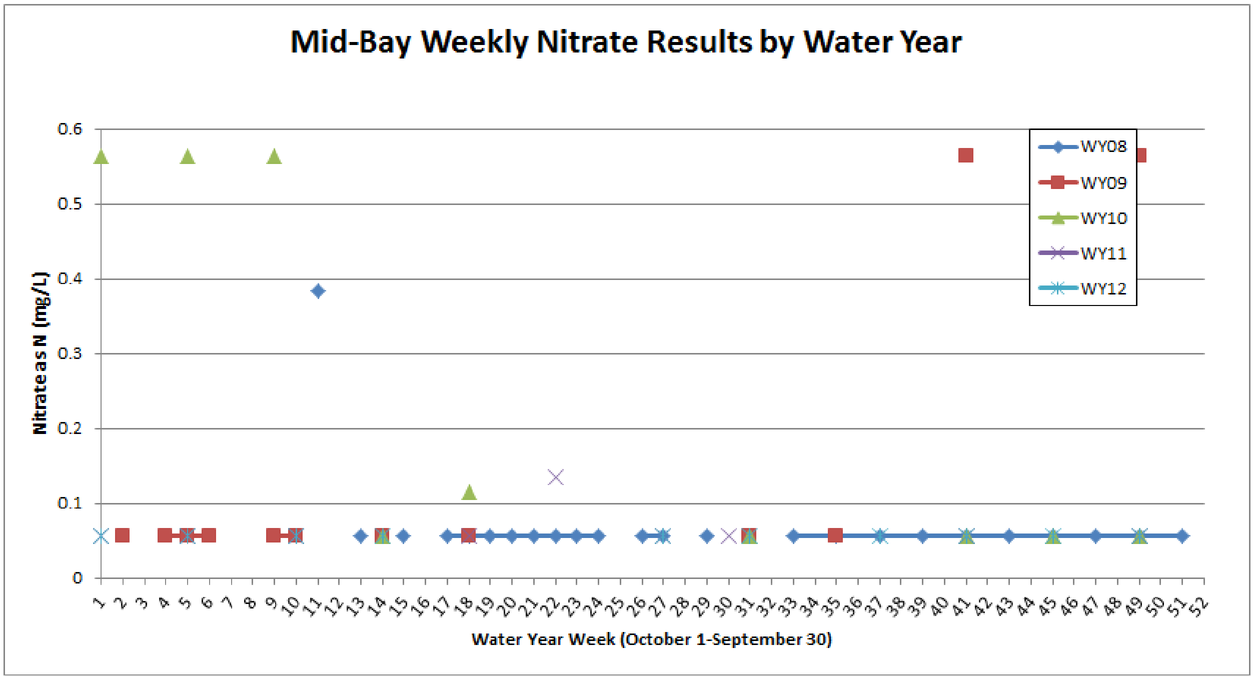
Above graphs has one omitted value, see graph below for complete results.

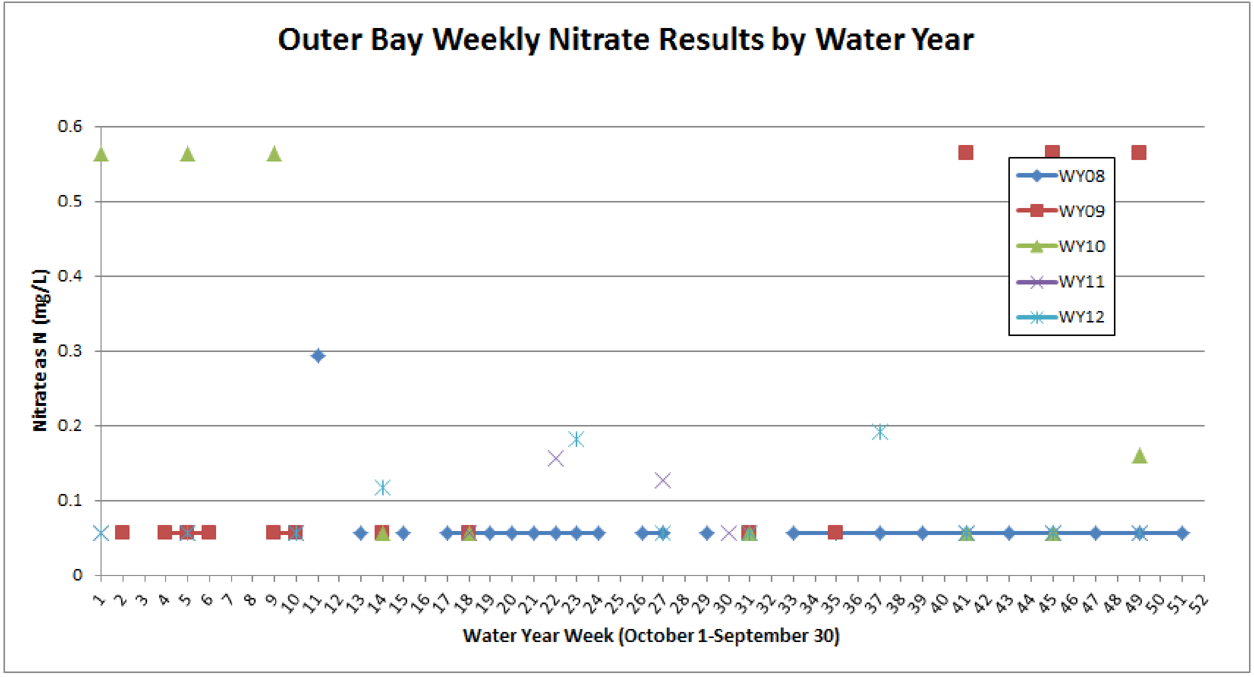




d. Tomales Bay Sites

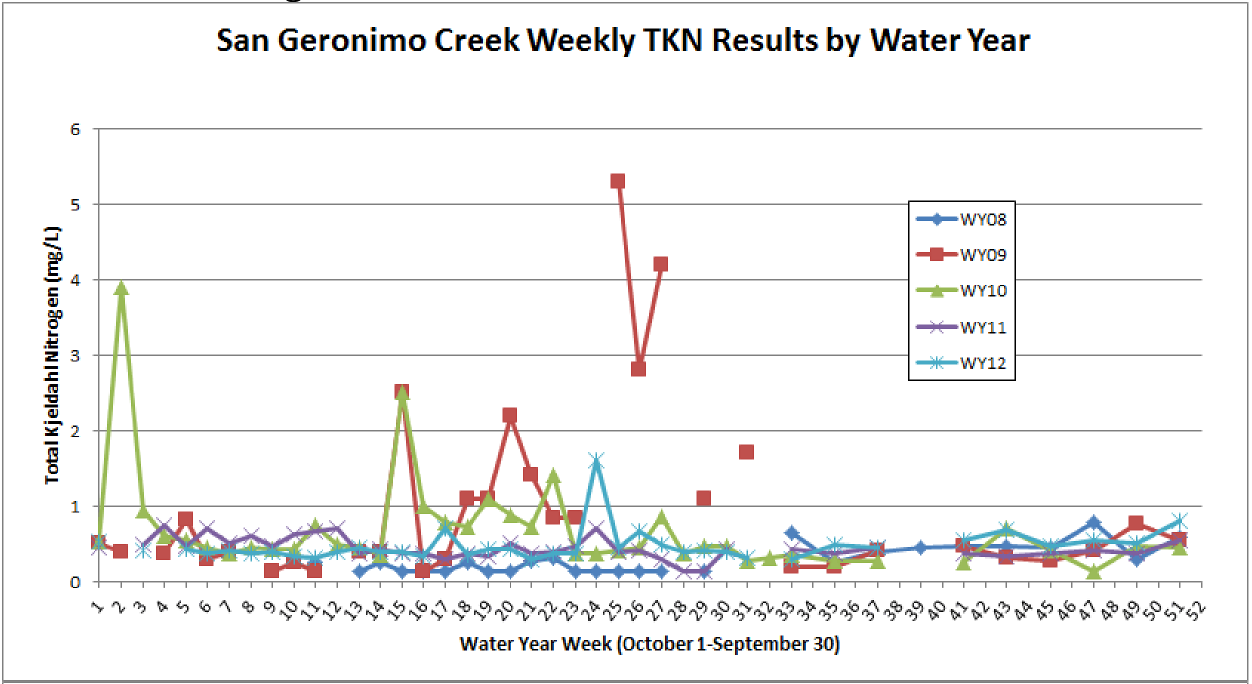


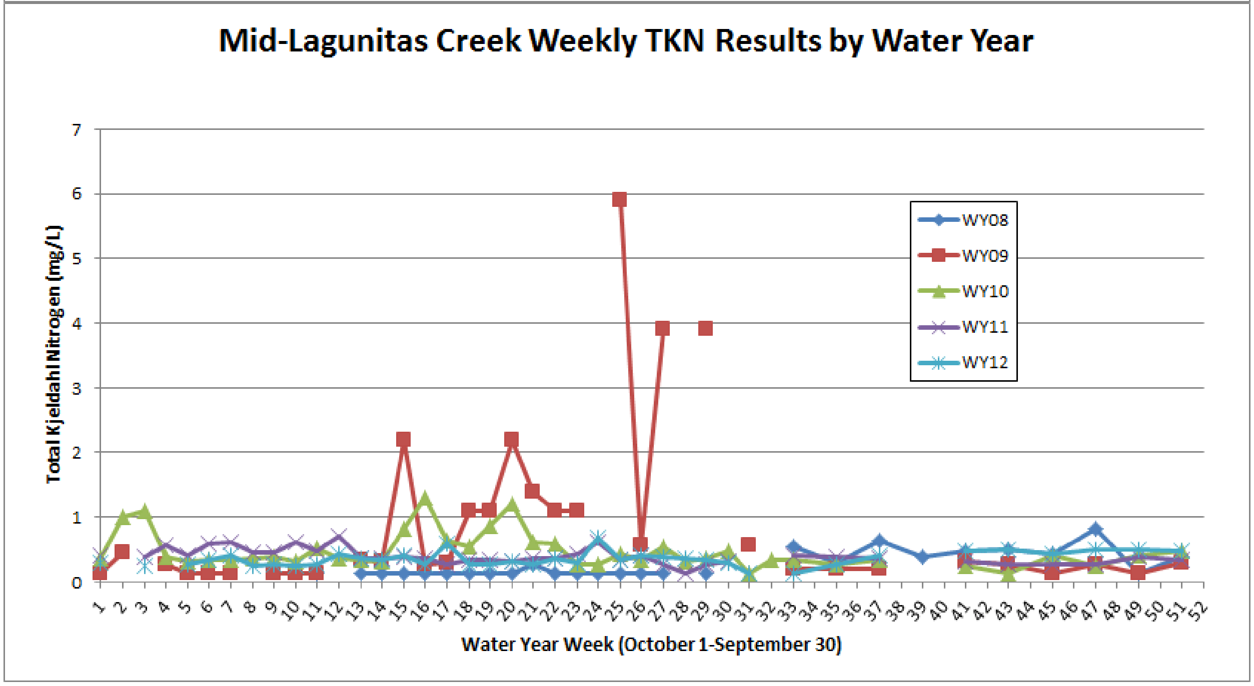

Mid-Bay Weekly Nitrate Results by Water Year
Nitrate as N (mg/L)
0
0.1
0.2
0.3
0.4
0.5
0.6
Water Year Week (October 1-September 30)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
WY08
WY09
WY10
WY11
WY12

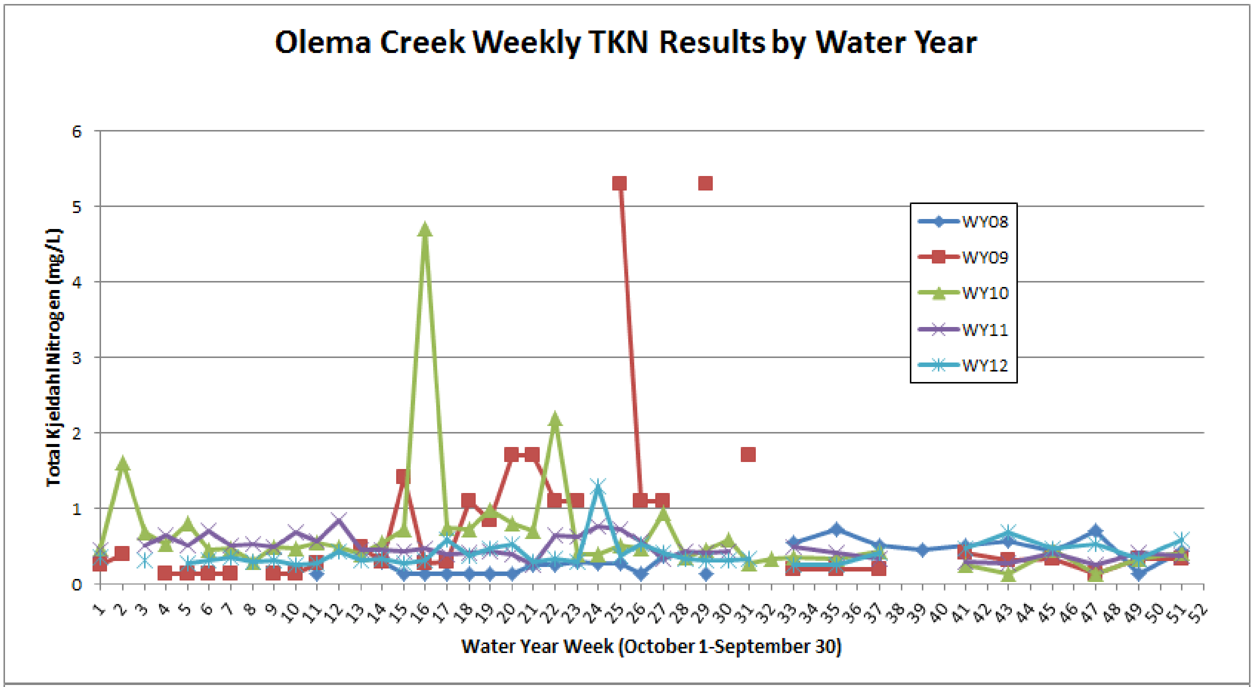

Outer Bay Weekly Nitrate Results by Water Year
Nitrate as N (mg/L)
0
0.1
0.2
0.3
0.4
0.5
0.6
Water Year Week (October 1-September 30)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
WY08
WY09
WY10
WY11
WY12

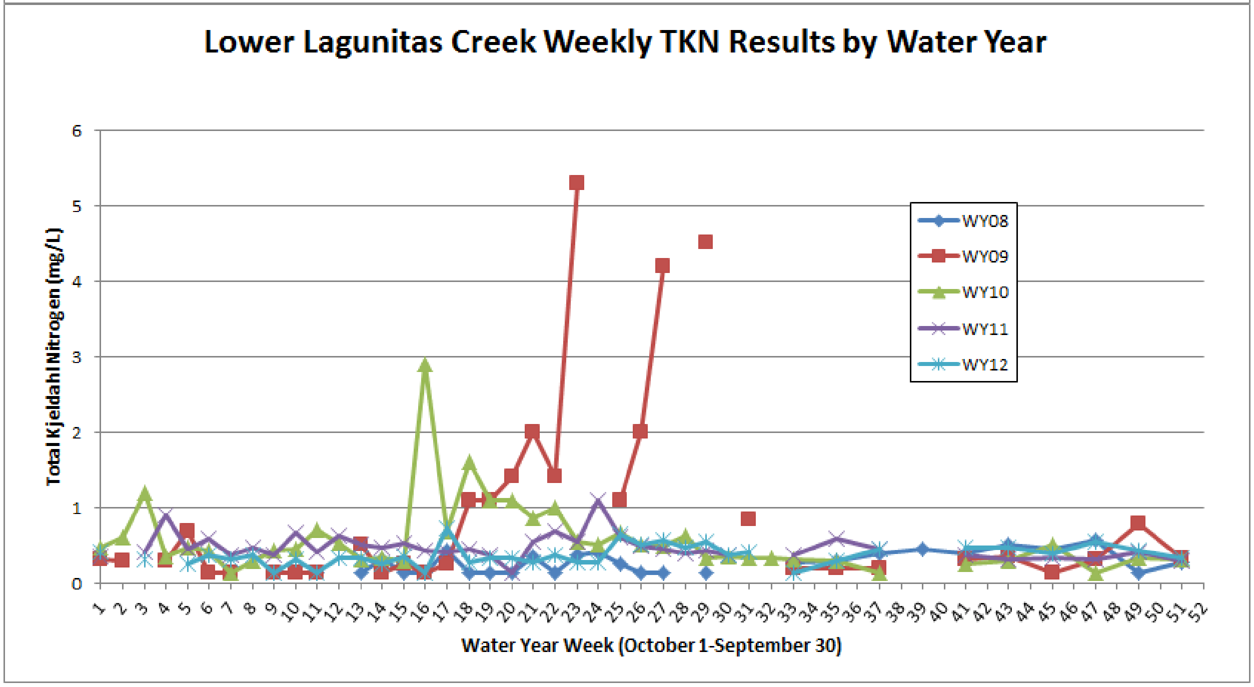
B. Total Kjeldahl Nitrogen (TKN) Results

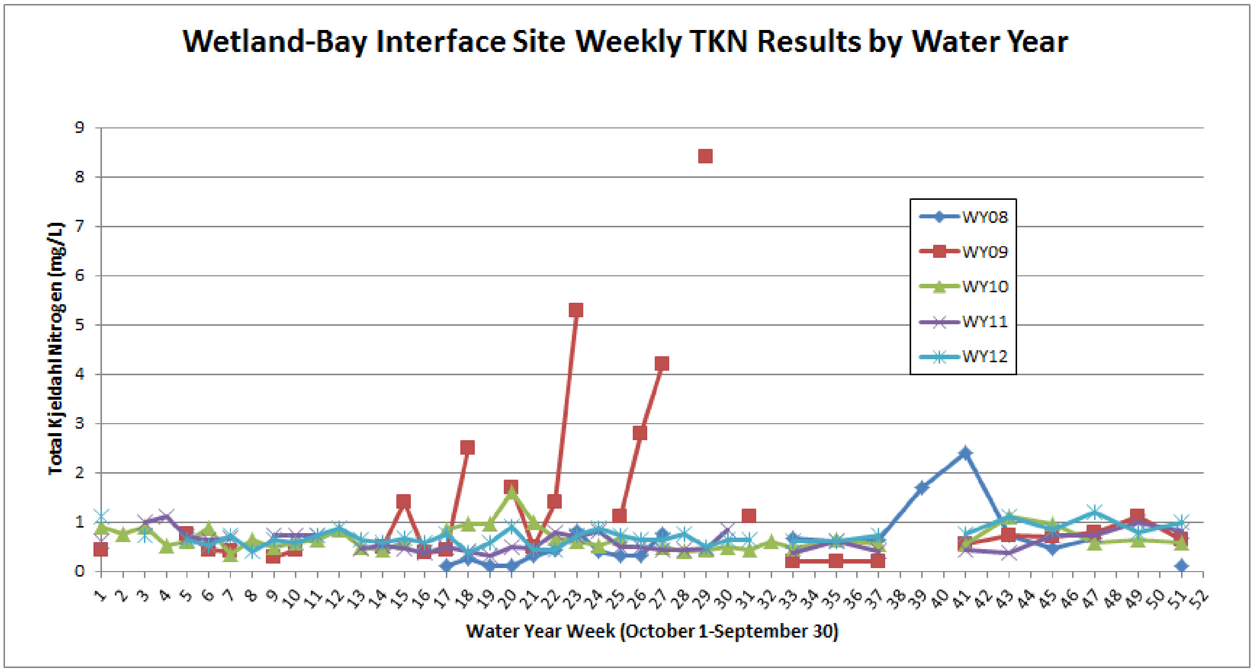
i. Lagunitas Creek Watershed Sites



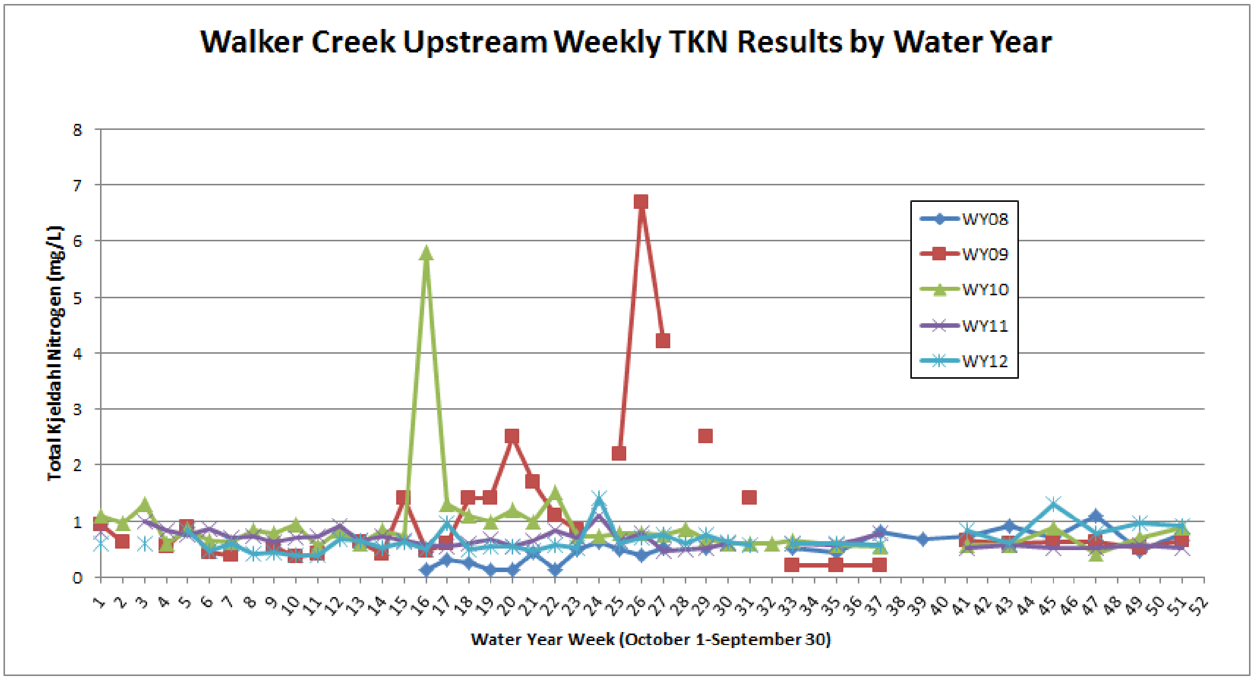


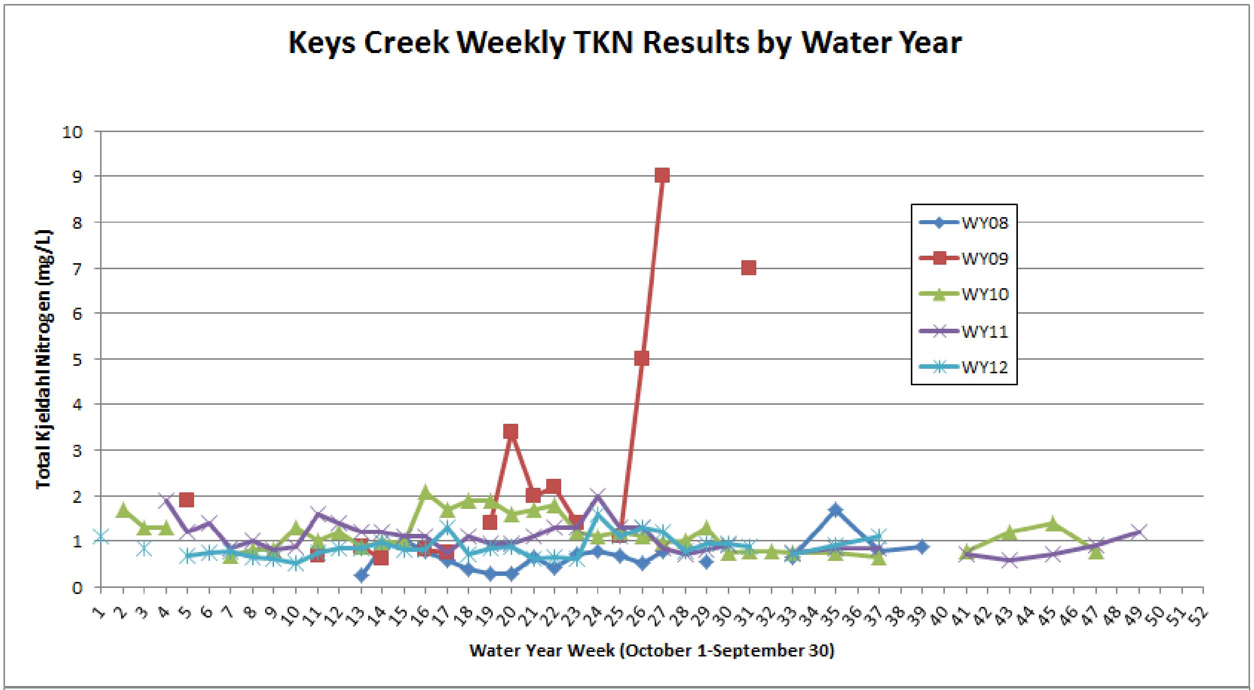

Olema Creek Weekly TKN Results by Water Year
Total Kjeldahl Nitrogen (mg/L)
0
1
2
3
4
5
6
Water Year Week (October 1-September 30)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
WY08
WY09
WY10
WY11
WY12

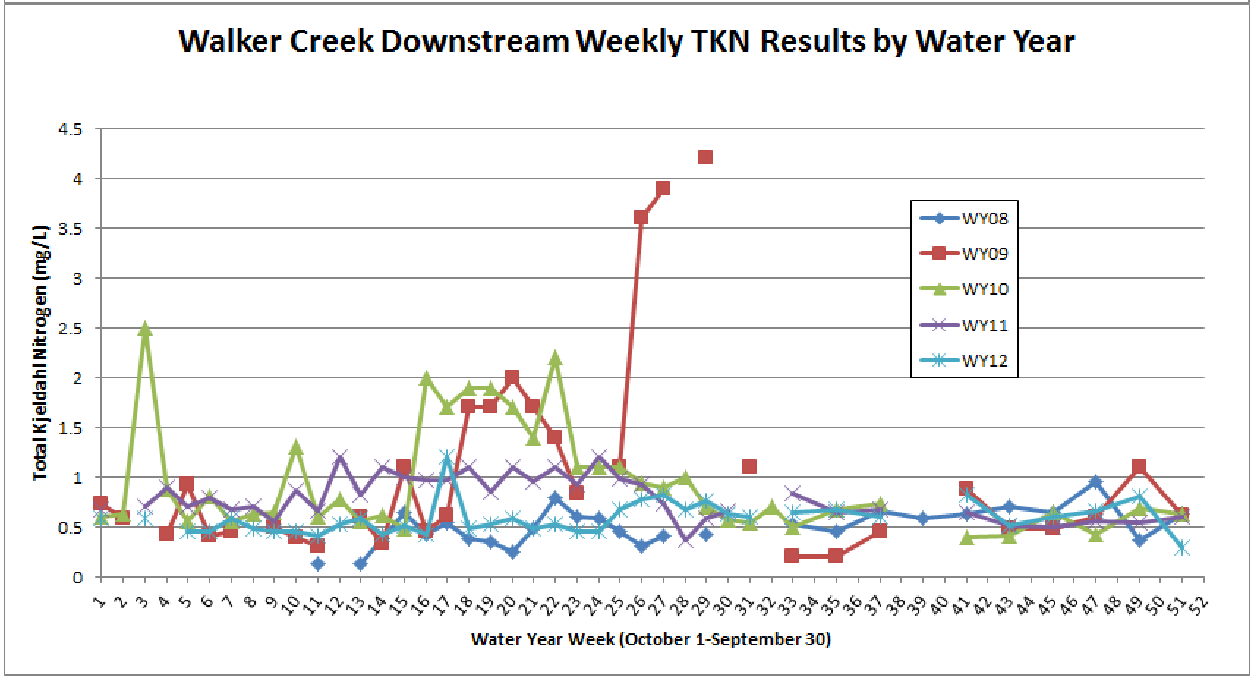

Lower Lagunitas Creek Weekly TKN Results by Water Year
Total Kjeldahl Nitrogen (mg/L)
0
1
2
3
4
5
6
Water Year Week (October 1-September 30)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
WY08
WY09
WY10
WY11
WY12



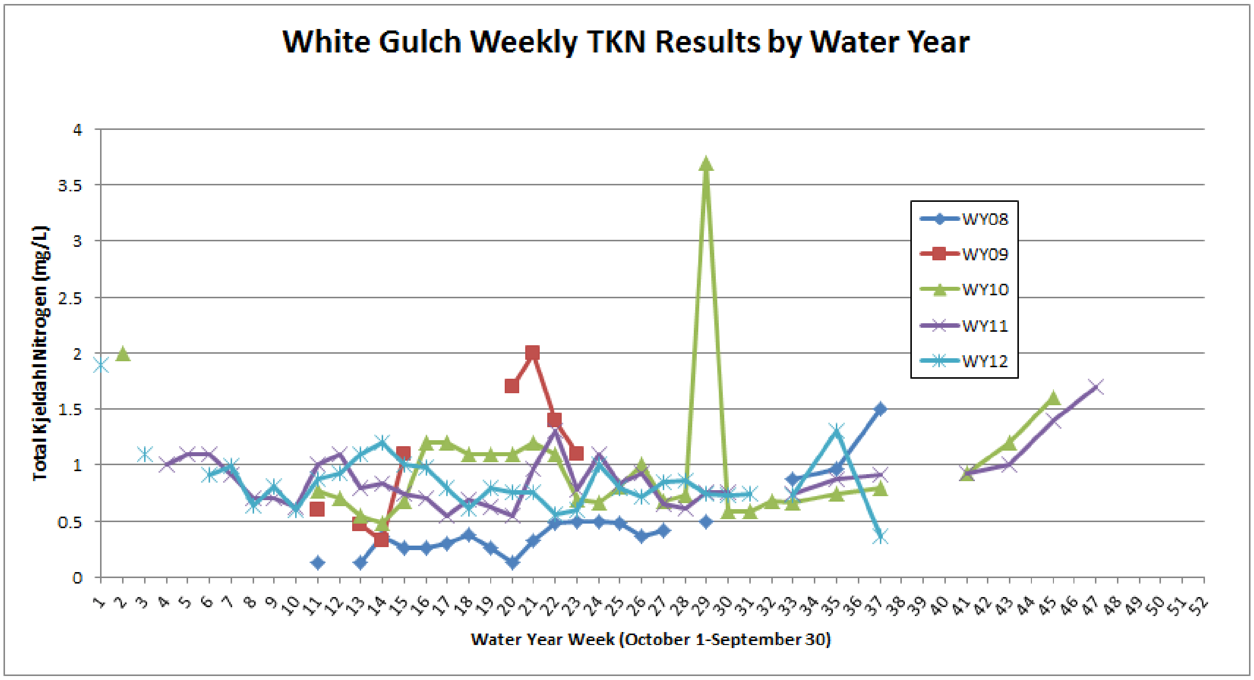
ii. Walker Creek Watershed Sites



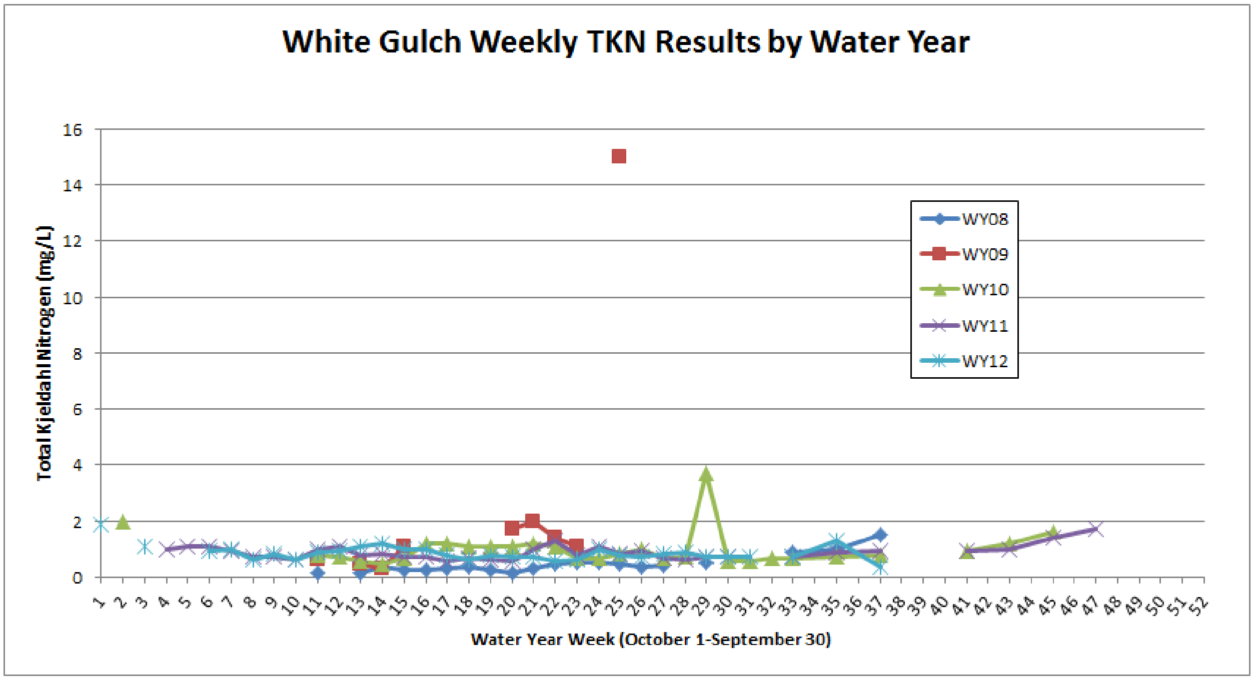

Keys Creek Weekly TKN Results by Water Year
Total Kjeldahl Nitrogen (mg/L)
0
1
2
3
4
5
6
7
8
9
10
Water Year Week (October 1-September 30)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
WY08
WY09
WY10
WY11
WY12

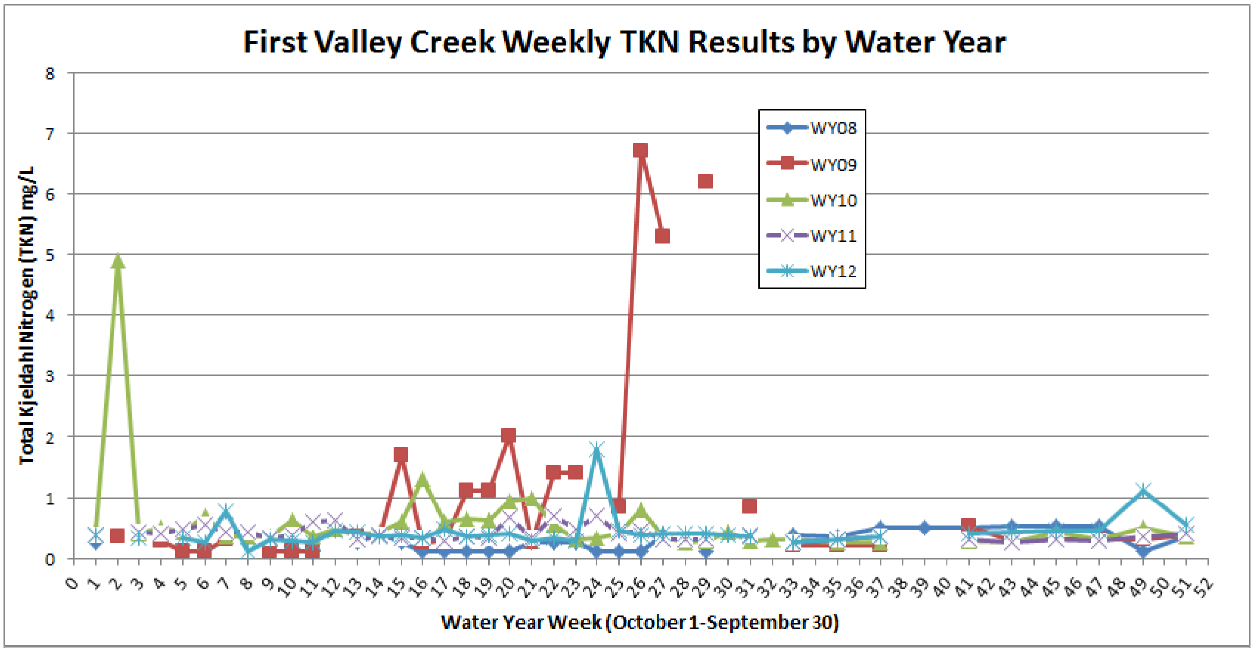

Walker Creek Downstream Weekly TKN Results by Water Year
Total Kjeldahl Nitrogen (mg/L)
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
Water Year Week (October 1-September 30)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
WY08
WY09
WY10
WY11
WY12

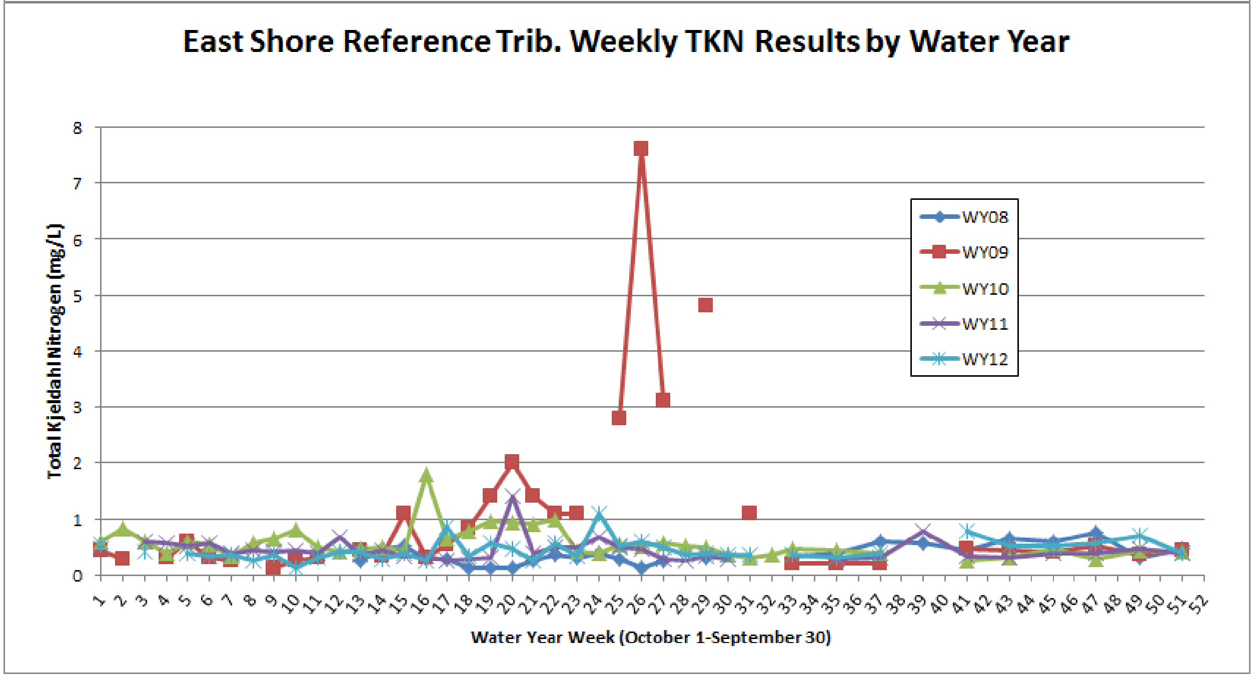
iii. Coastal Tributaries Watershed Sites

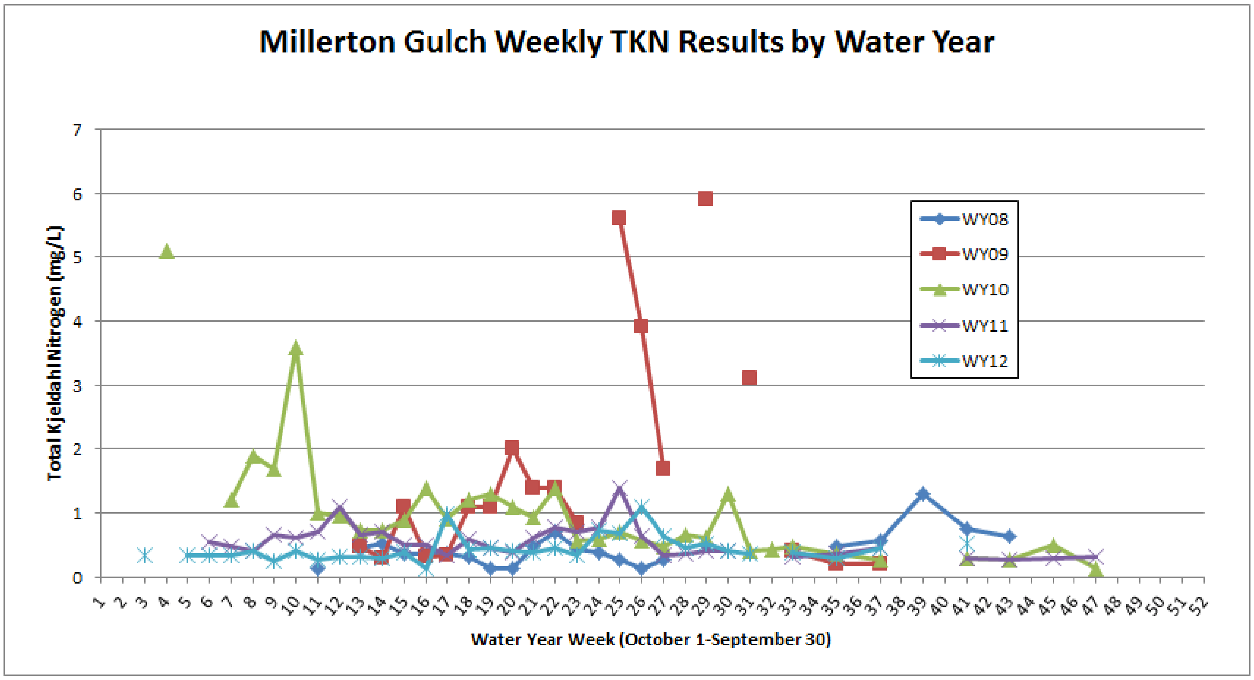


Above graphs has one omitted value, see graph below for complete results.

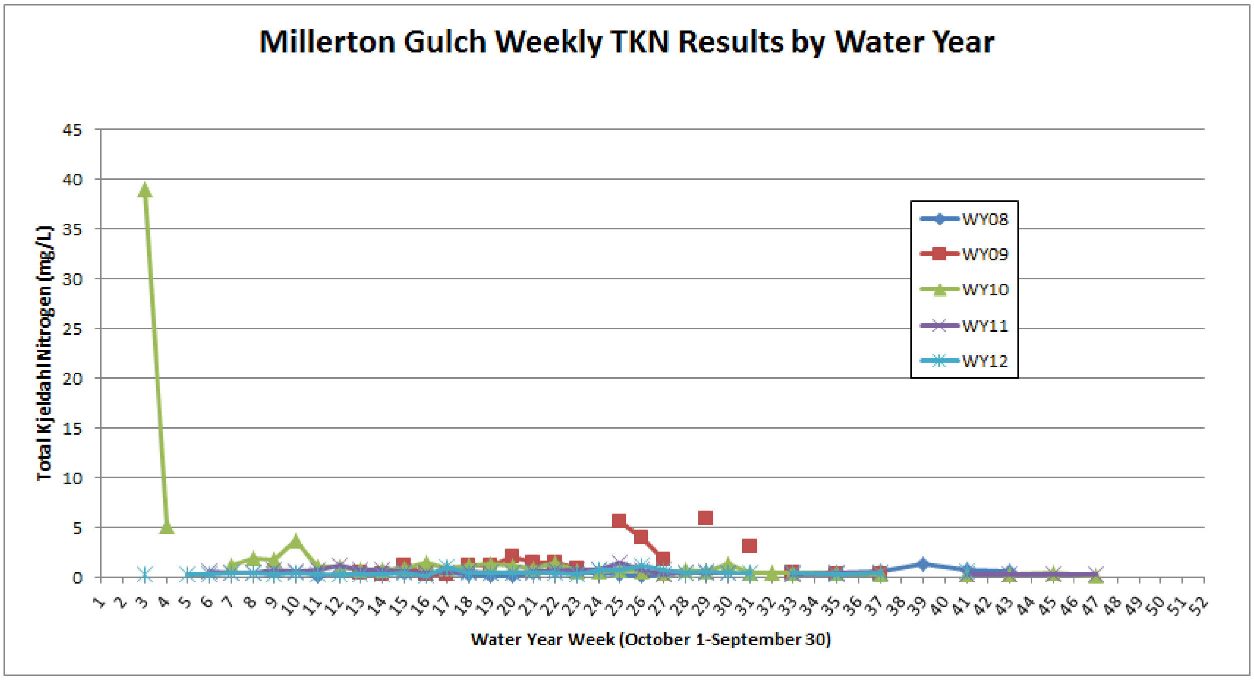



First Valley Creek Weekly TKN Results by Water Year
Total Kjeldahl Nitrogen (TKN) mg/L
0
1
2
3
4
5
6
7
8
Water Year Week (October 1-September 30)
WY08
WY09
WY10
WY11
WY12

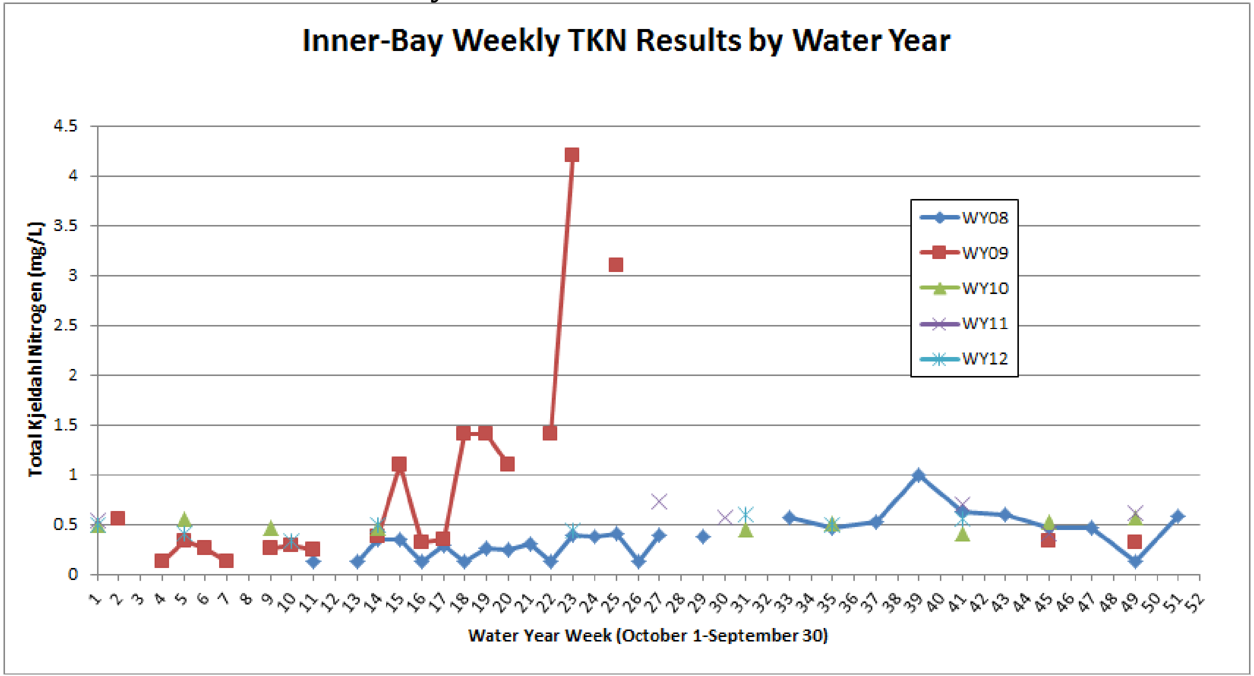

East Shore Reference Trib. Weekly TKN Results by Water Year
Total Kjeldahl Nitrogen (mg/L)
0
1
2
3
4
5
6
7
8
Water Year Week (October 1-September 30)
WY08
WY09
WY10
WY11
WY12

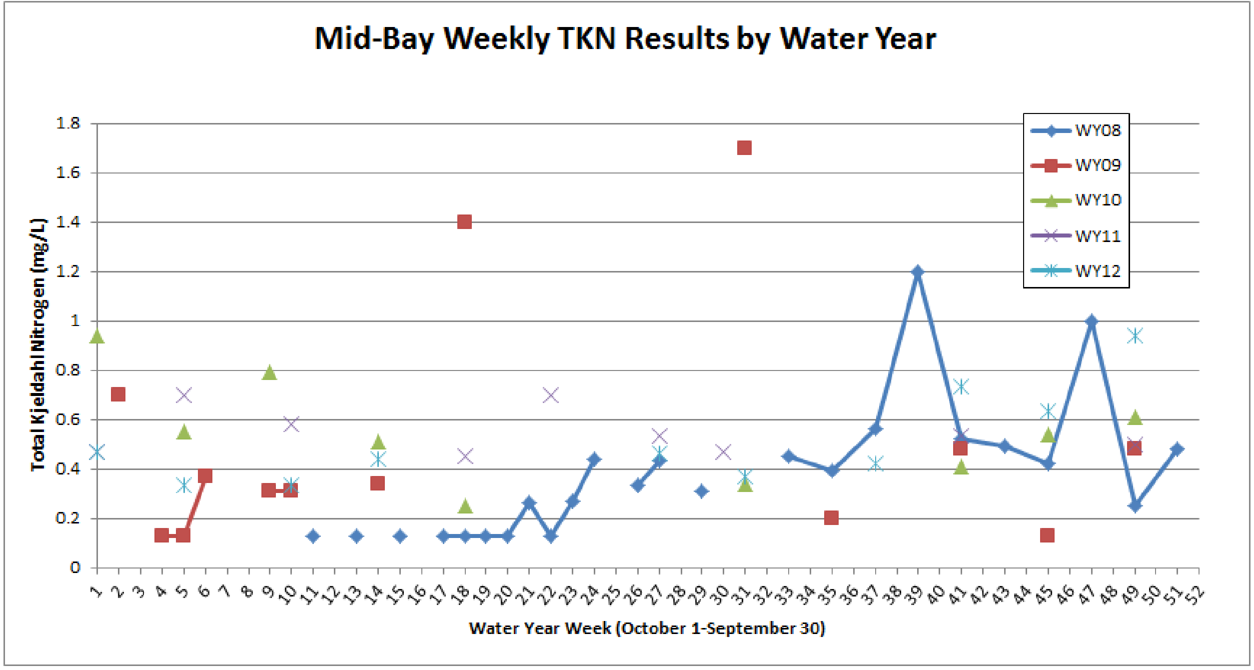


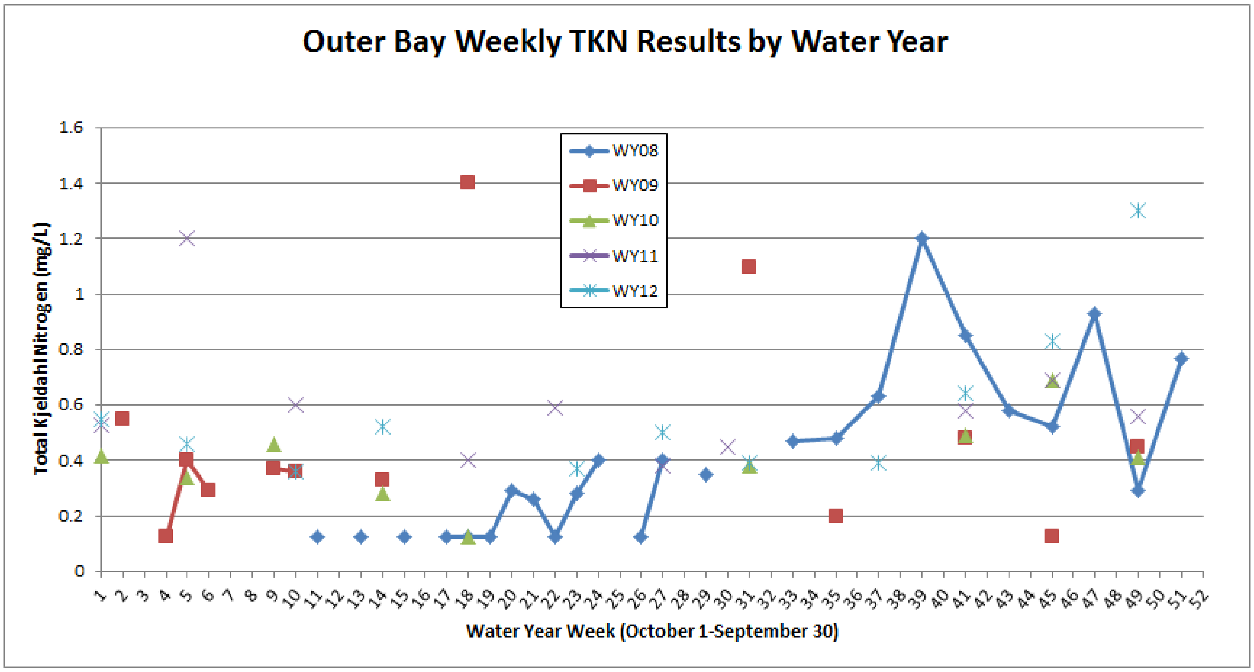
Above graphs has one omitted value, see graph below for complete results.



d. Tomales Bay Sites

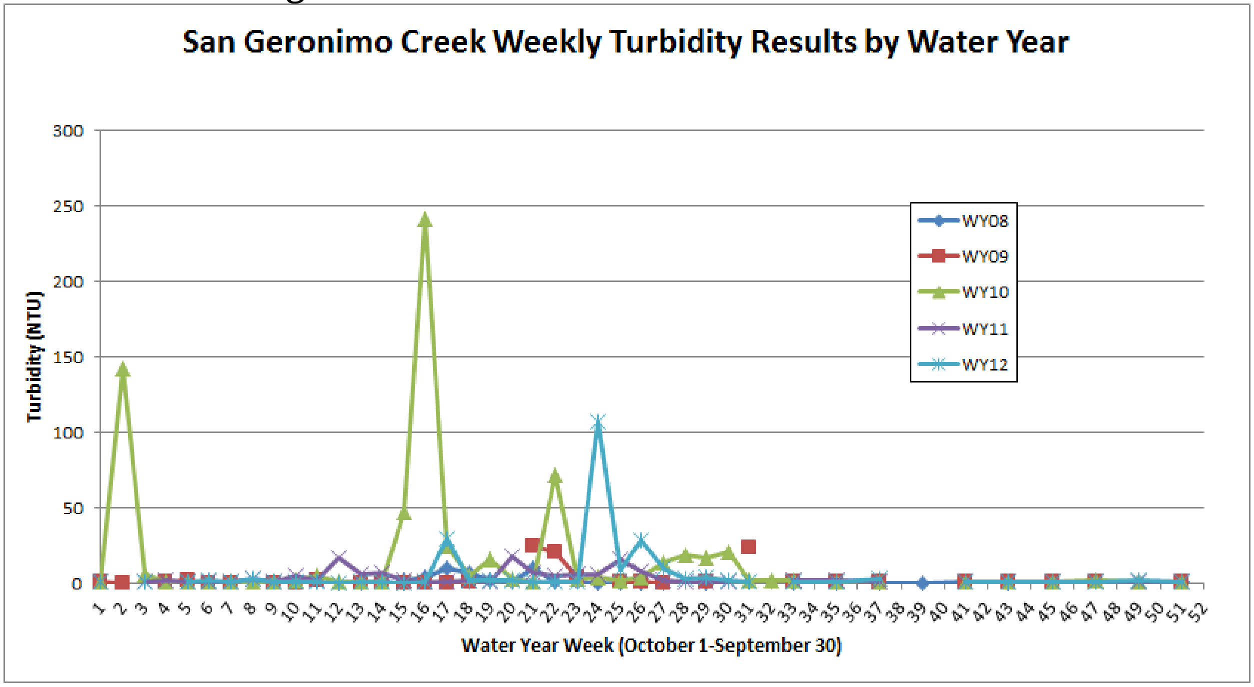


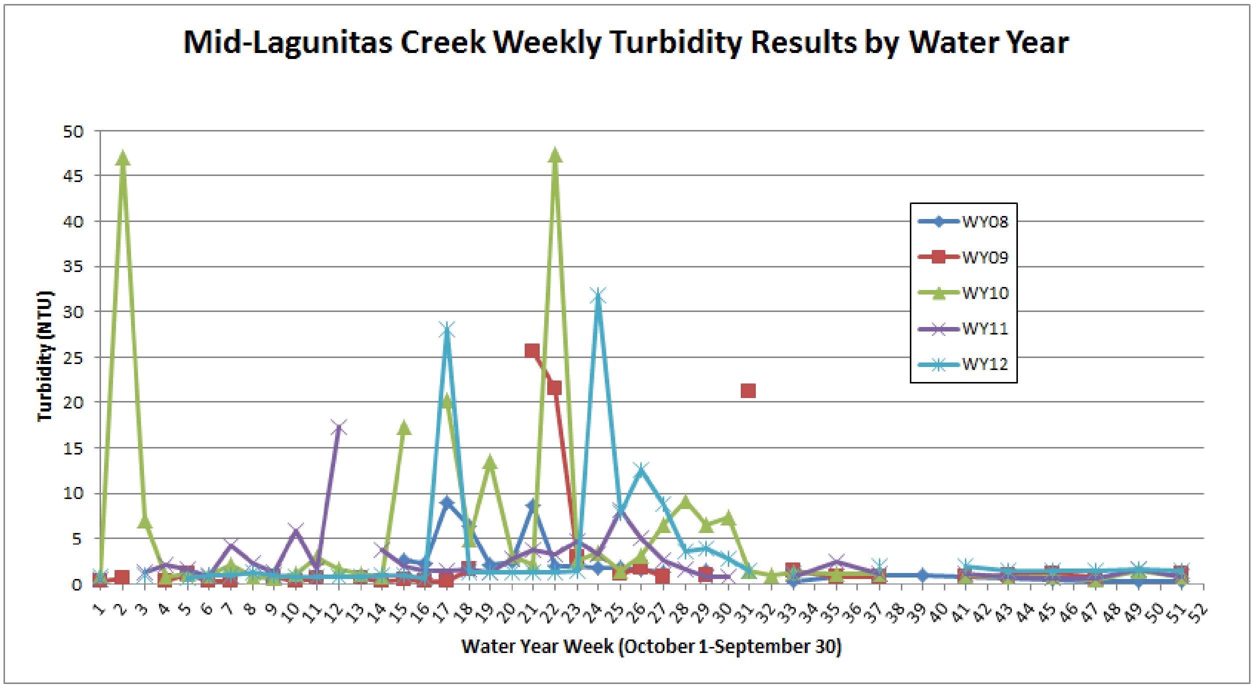




C. Turbidity Results

i. Lagunitas Creek Watershed Sites





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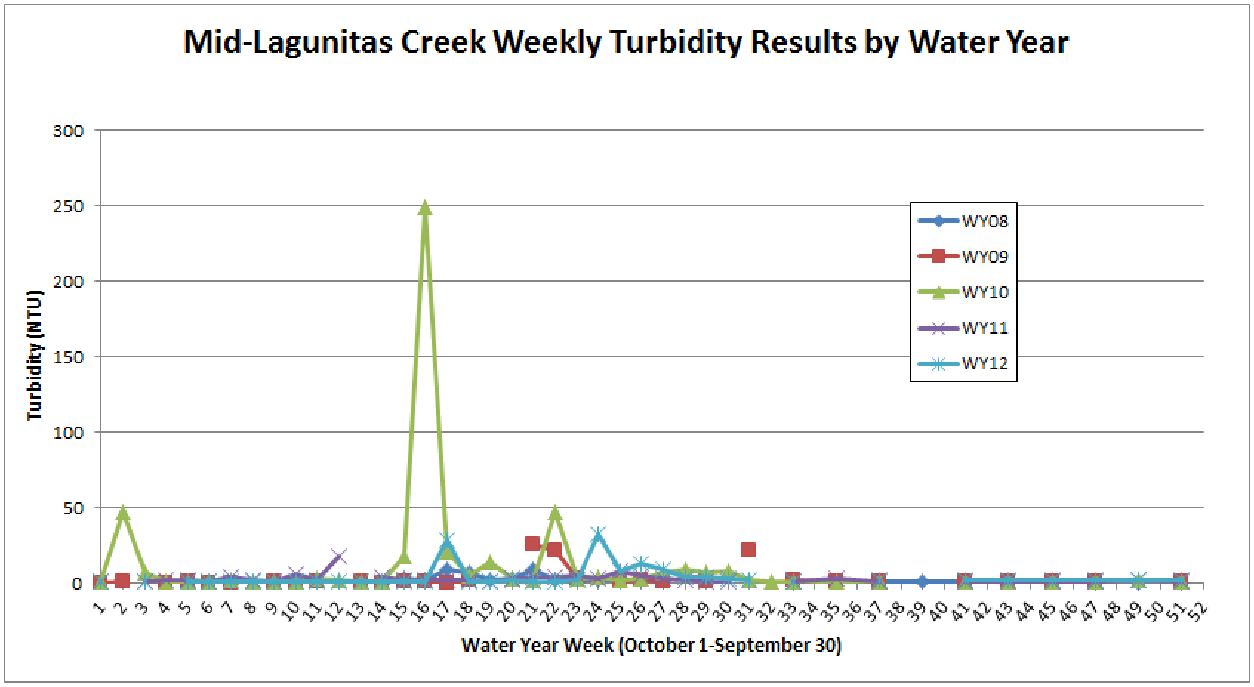
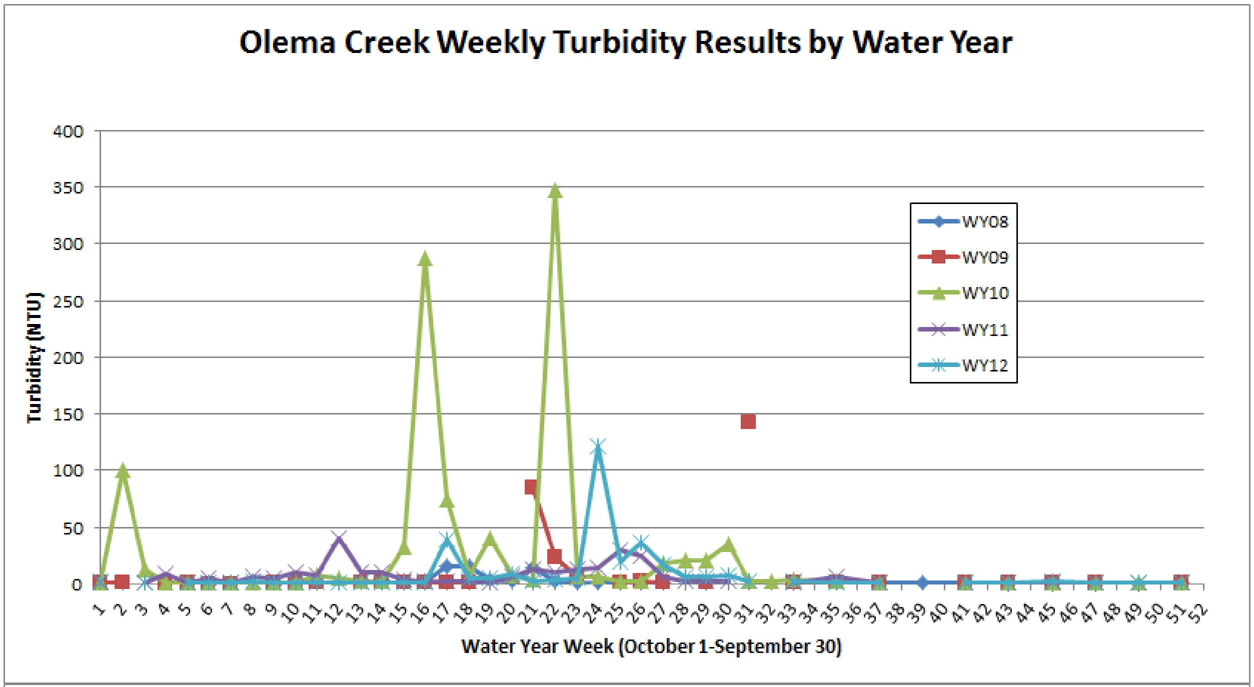
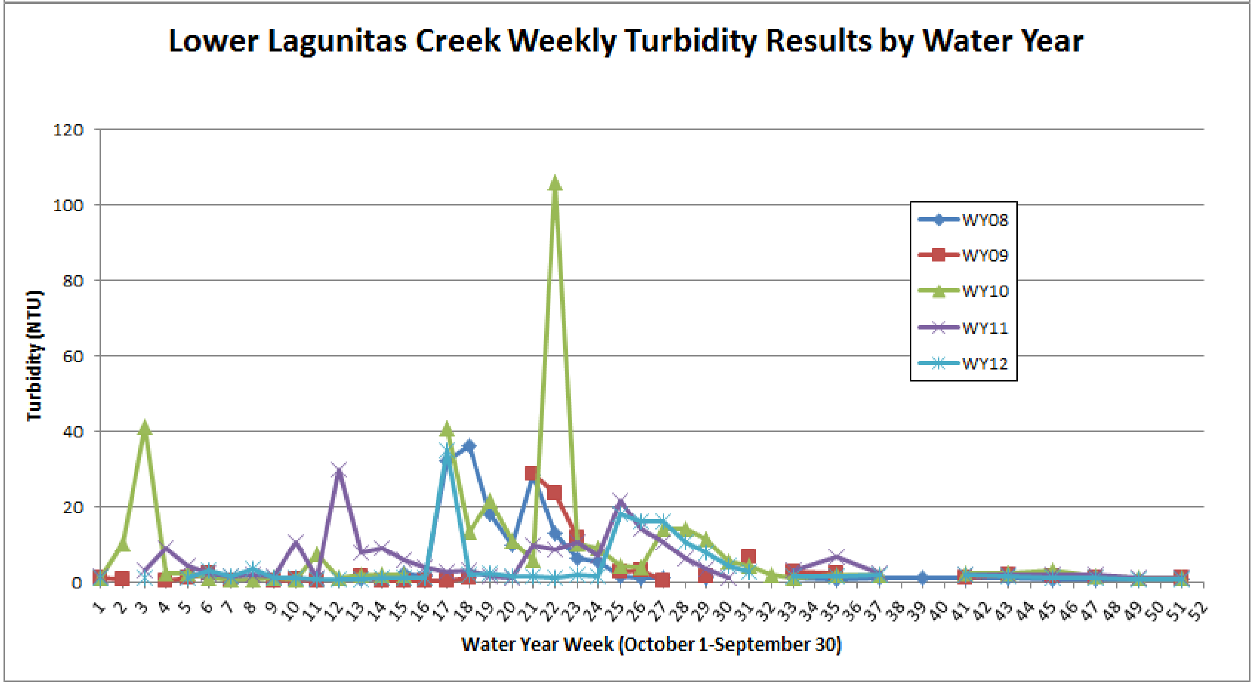
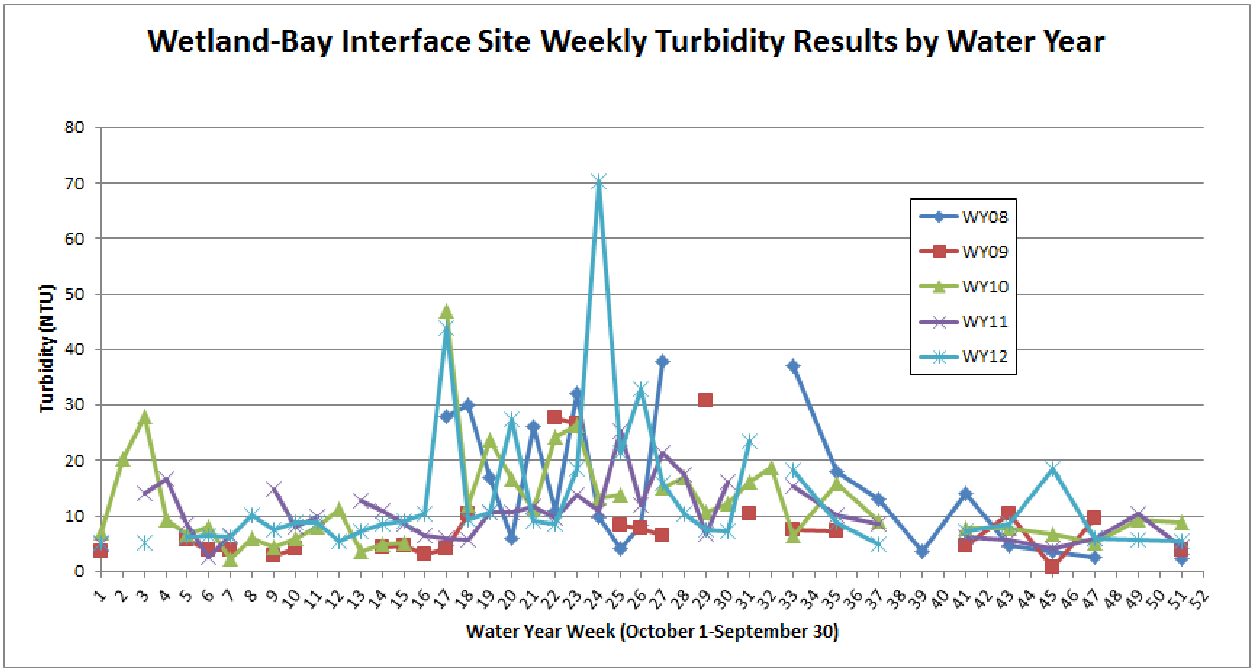
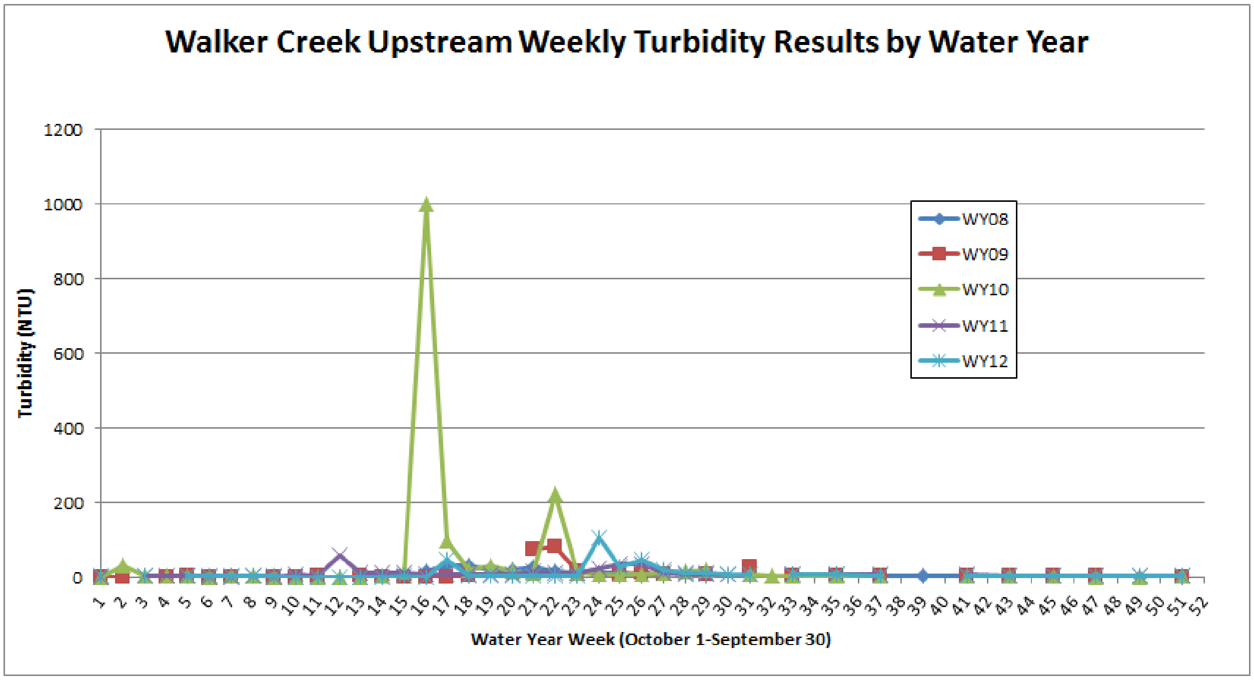


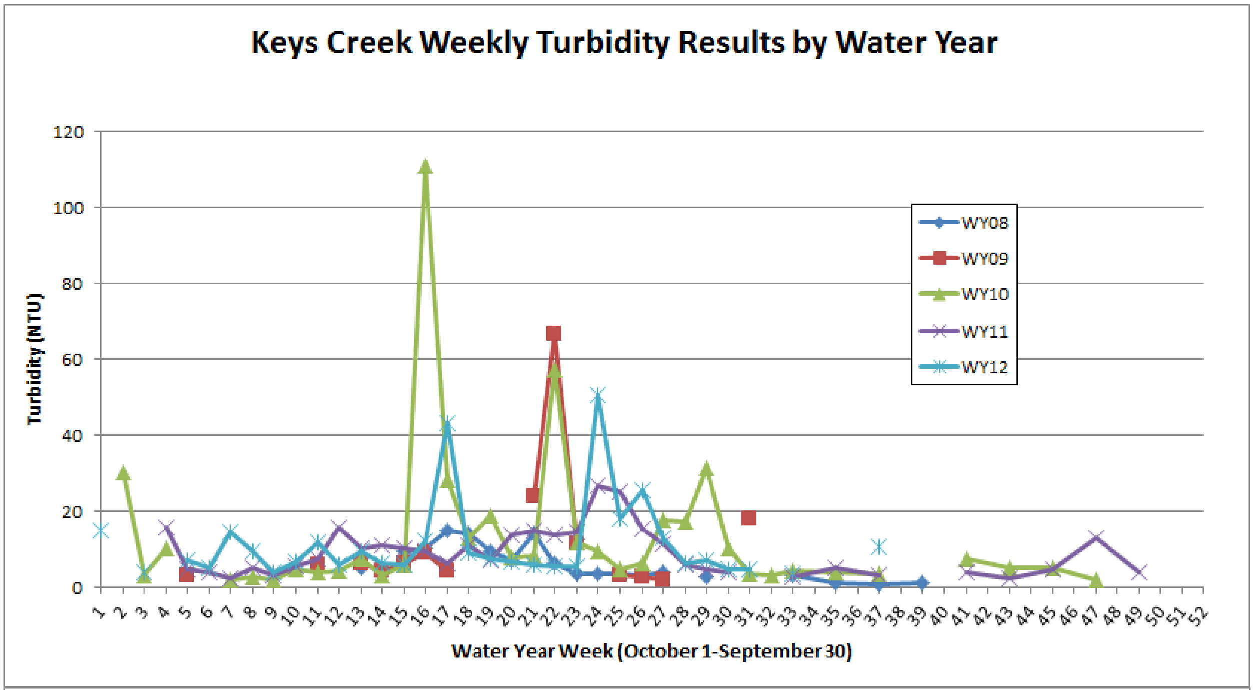

Olema Creek Weekly Turbidity Results by Water Year
Turbidity (NTU)
400
350
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
Water Year Week (October 1-September 30)
WY08
WY09
WY10
WY11
WY12

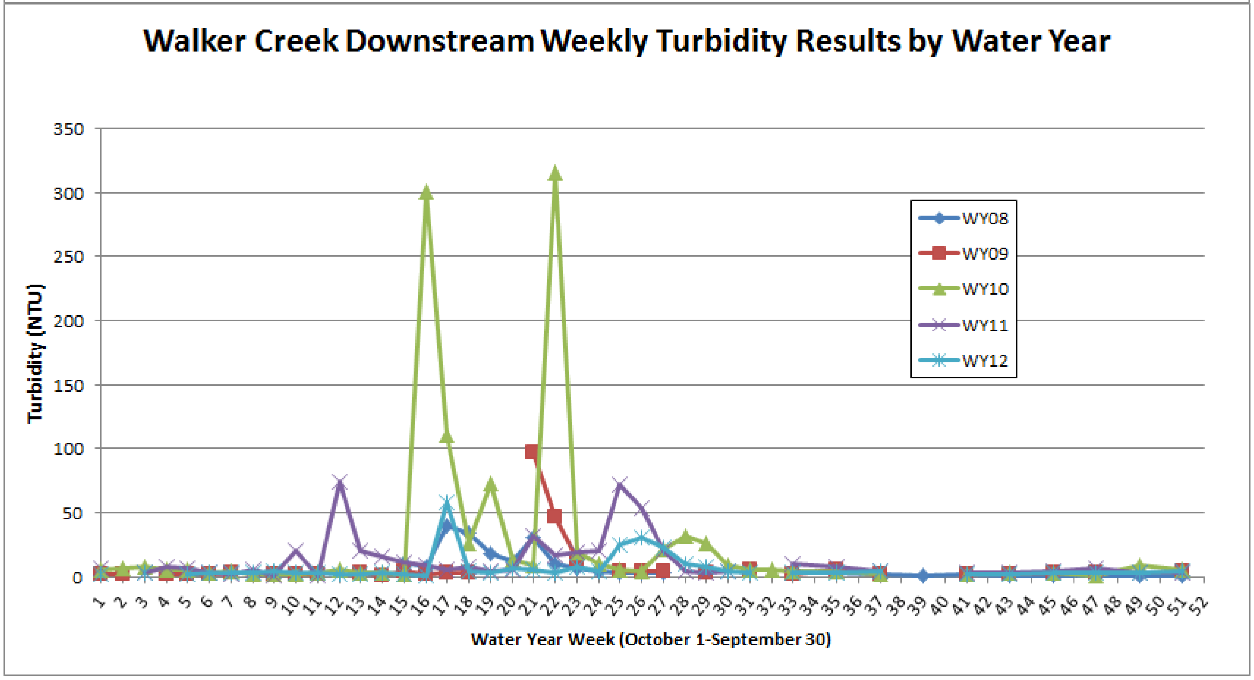

Lower Lagunitas Creek Weekly Turbidity Results by Water Year
Turbidity (NTU)
120
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
Water Year Week (October 1-September 30)
WY08
WY09
WY10
WY11
WY12



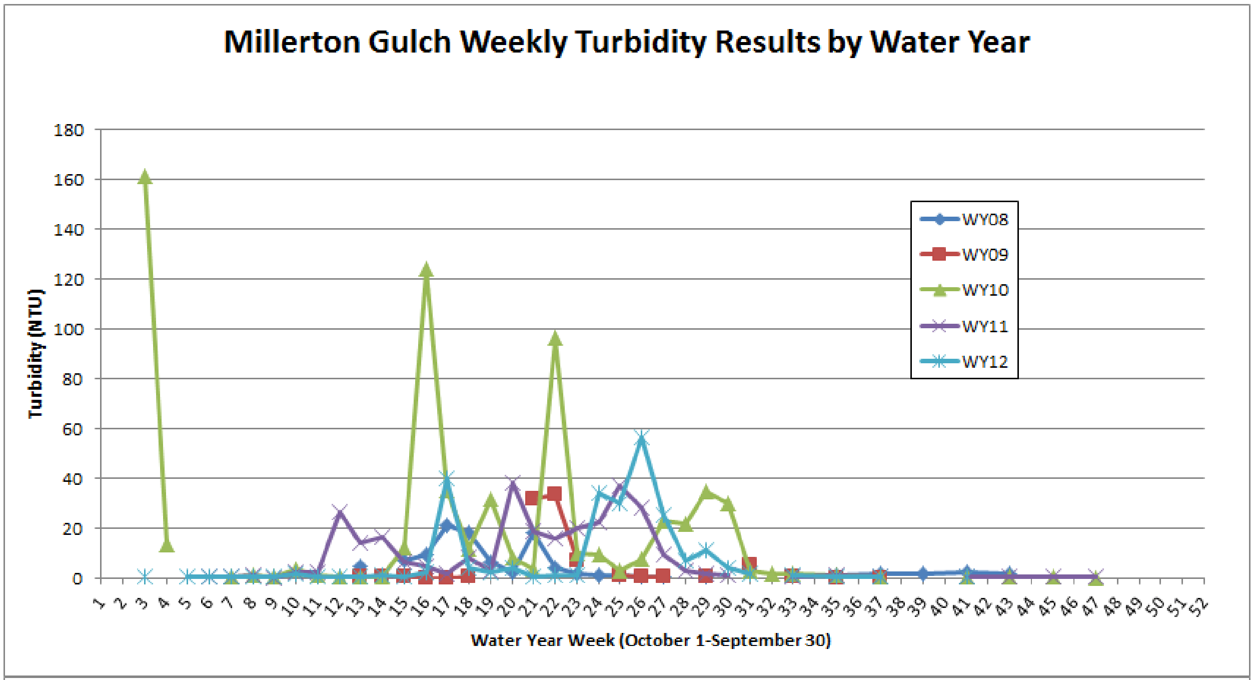
ii. Walker Creek Watershed Sites

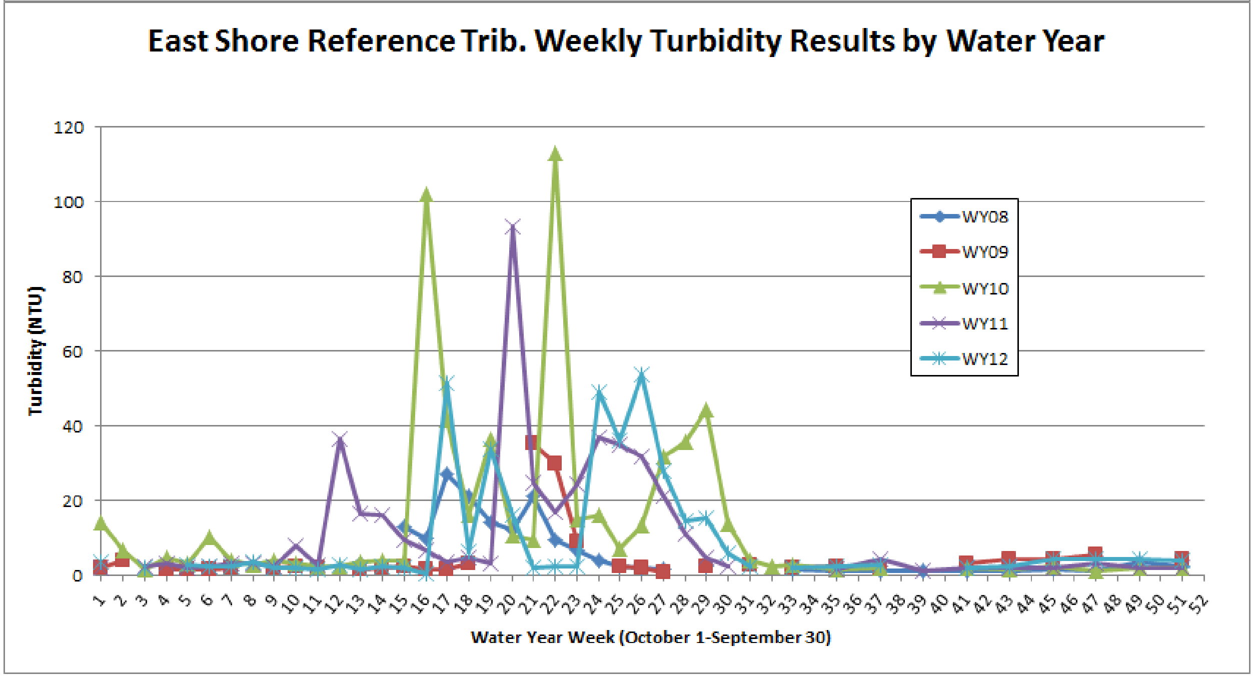


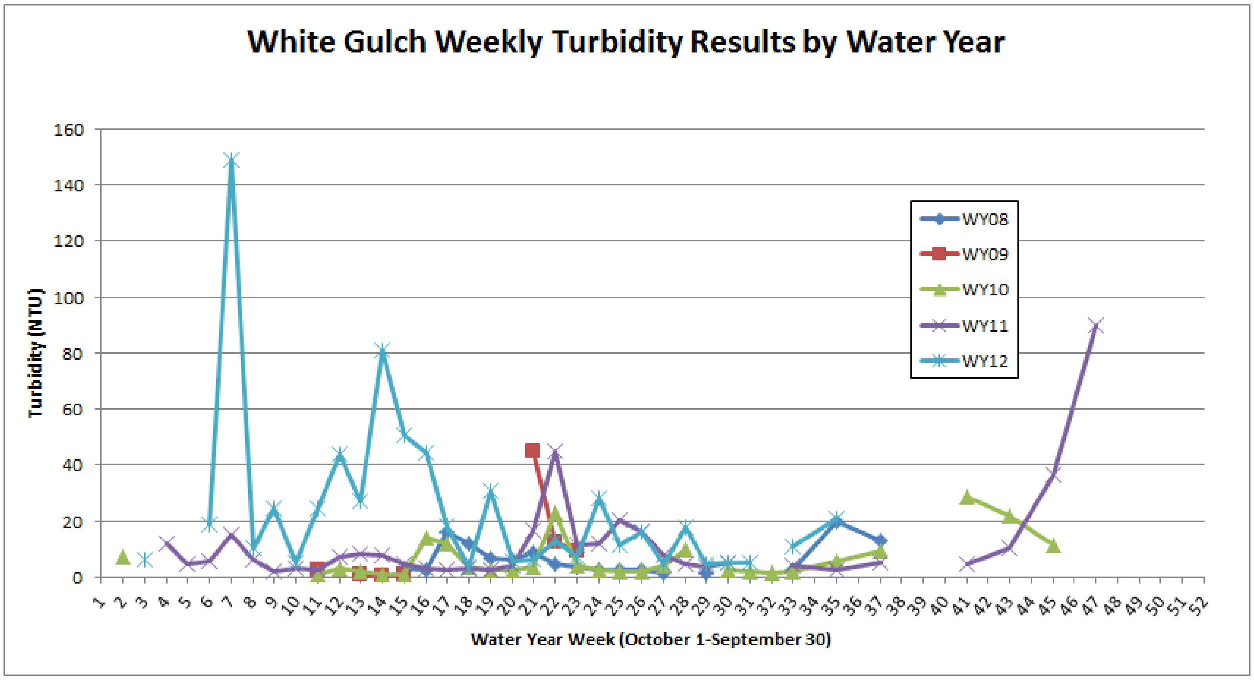

Keys Creek Weekly Turbidity Results by Water Year
Turbidity (NTU)
0
20
40
60
80
100
120
WY08
WY09
WY10
WY11
WY12
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
Water Year Week (October 1-September 30)


Walker Creek Downstream Weekly Turbidity Results by Water Year
Turbidity (NTU)
0
50
100
150
200
250
300
350
WY08
WY09
WY10
WY11
WY12
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
Water Year Week (October 1-September 30)

iii. Coastal Tributaries Watershed Sites







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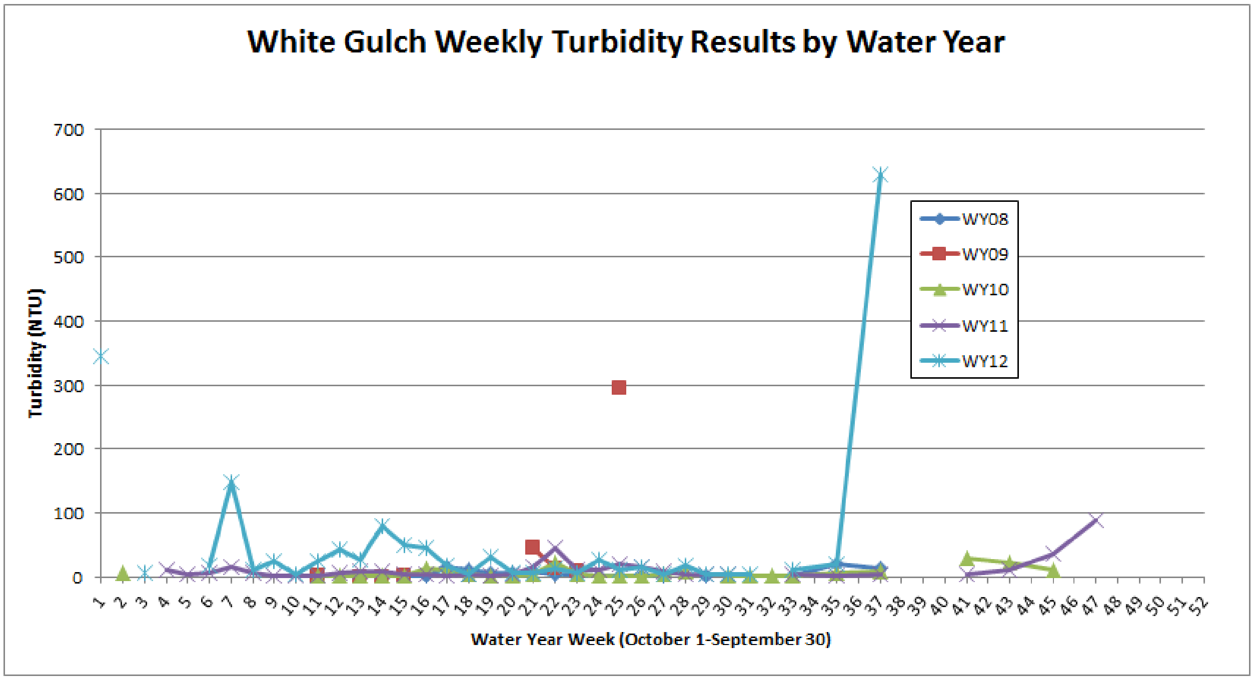
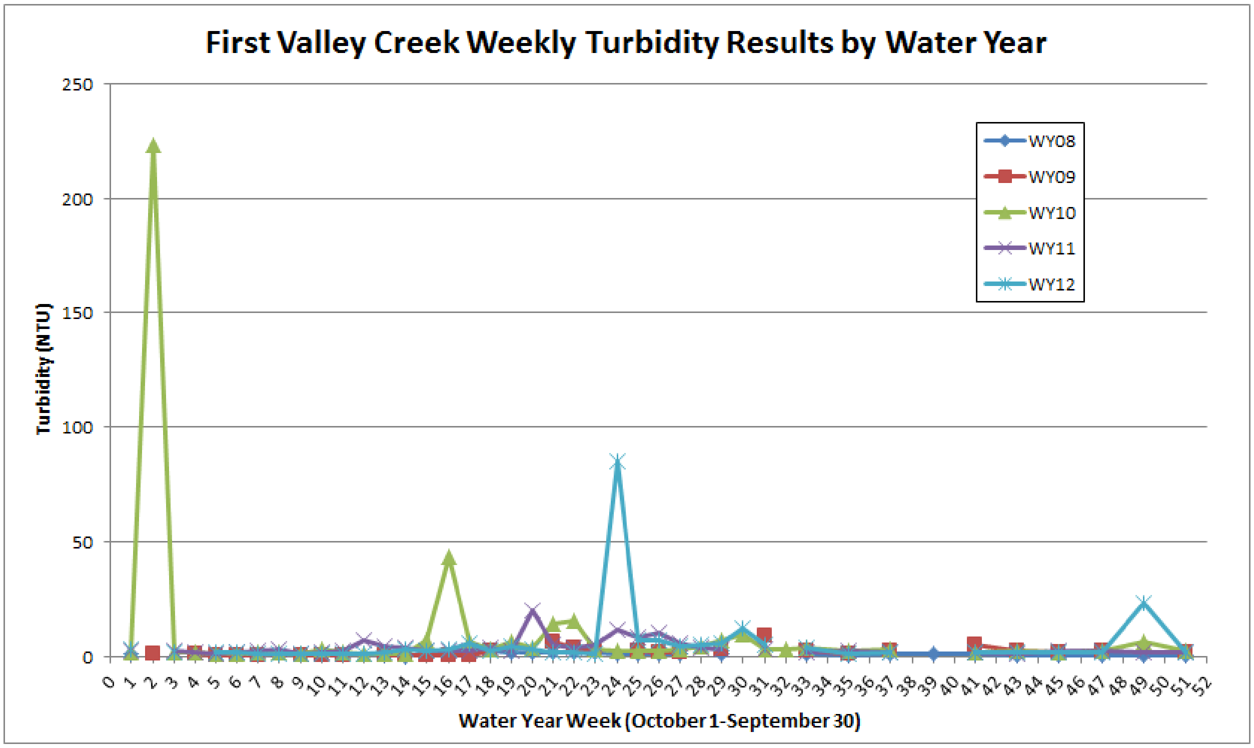
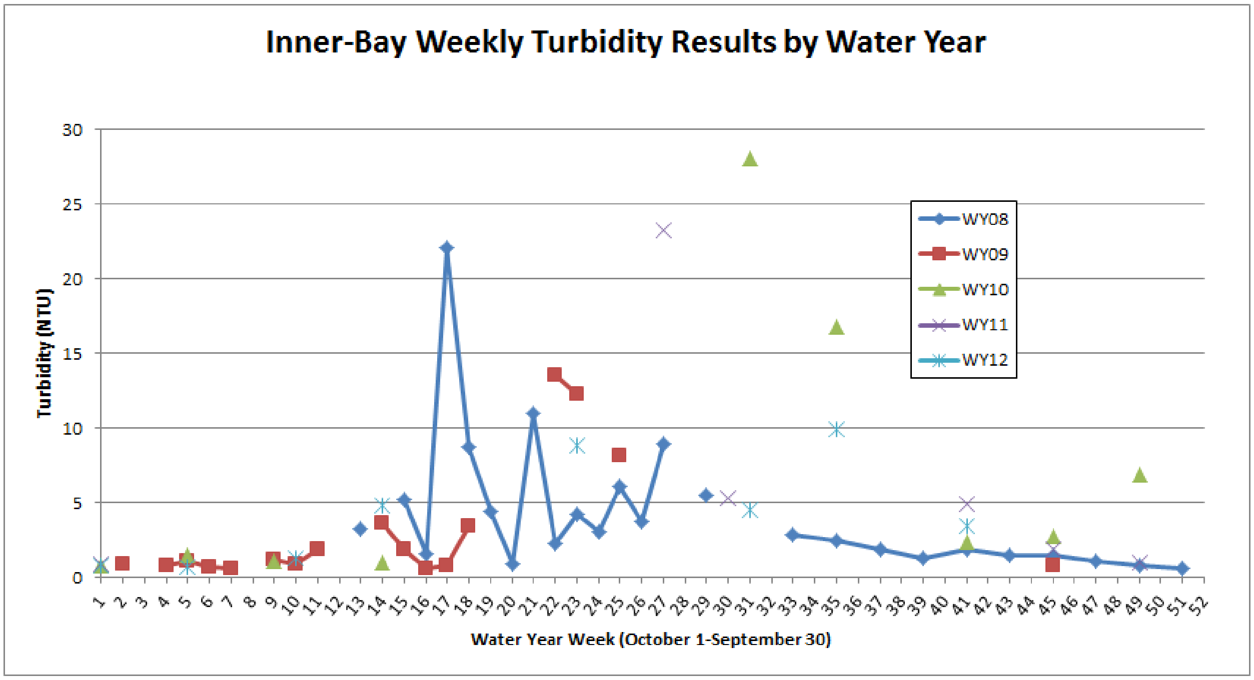
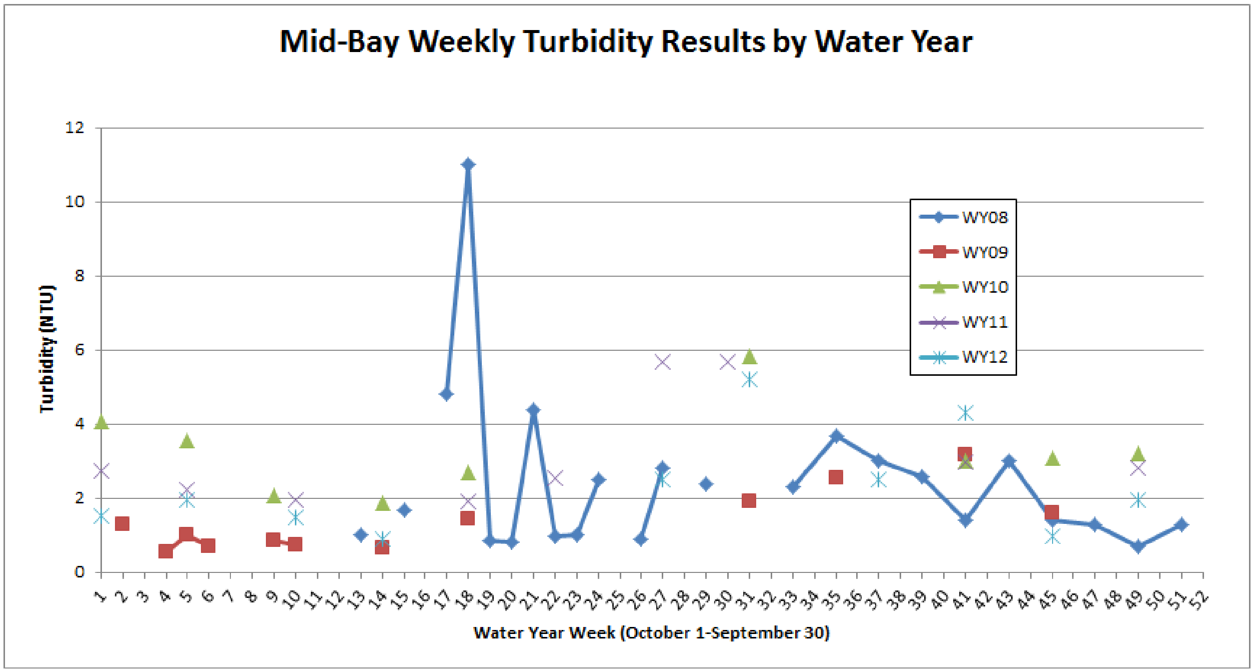
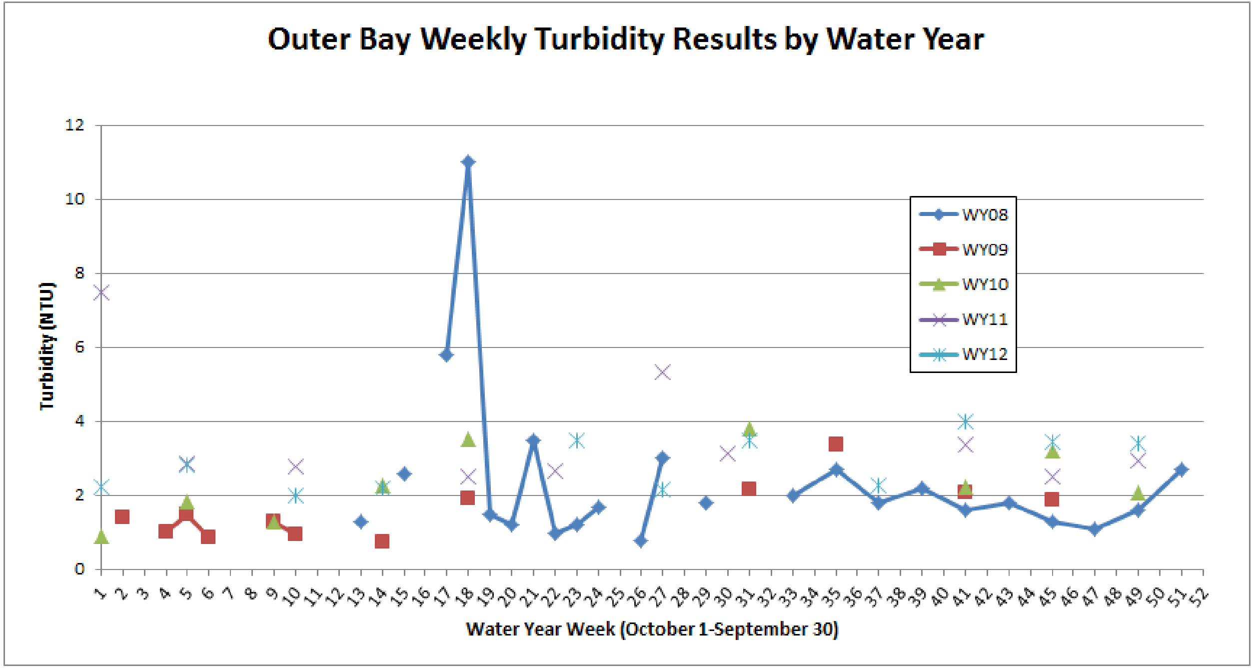




iv. Tomales Bay Sites

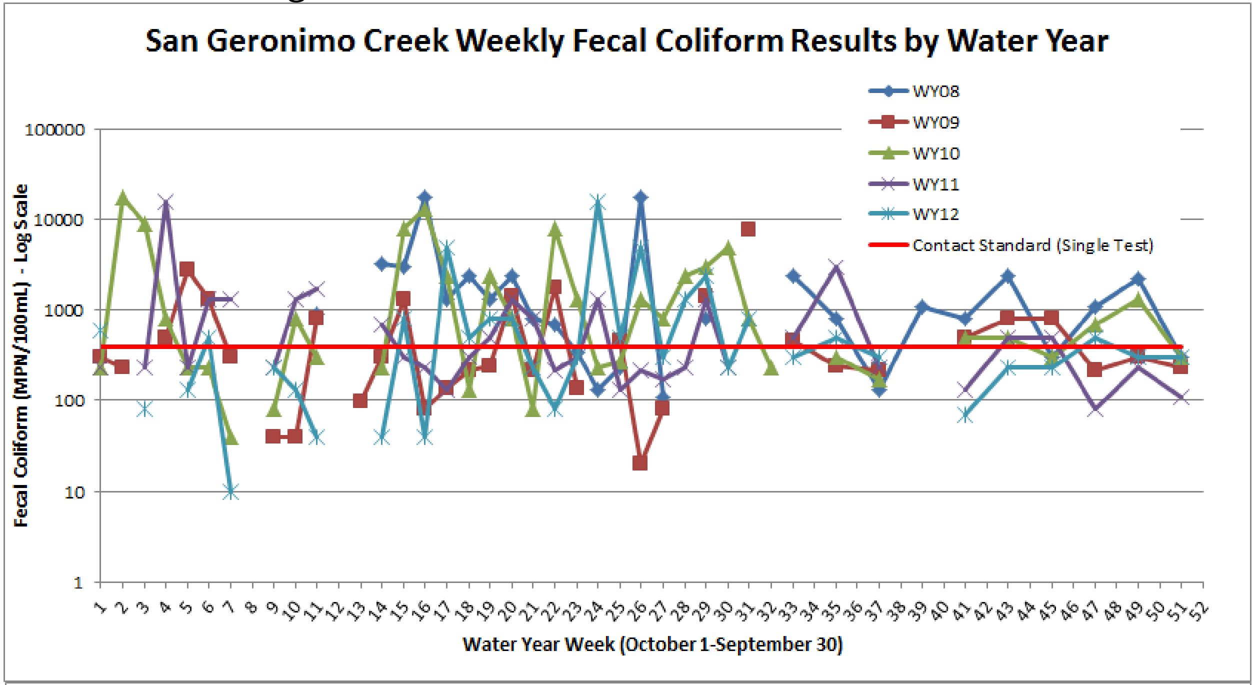


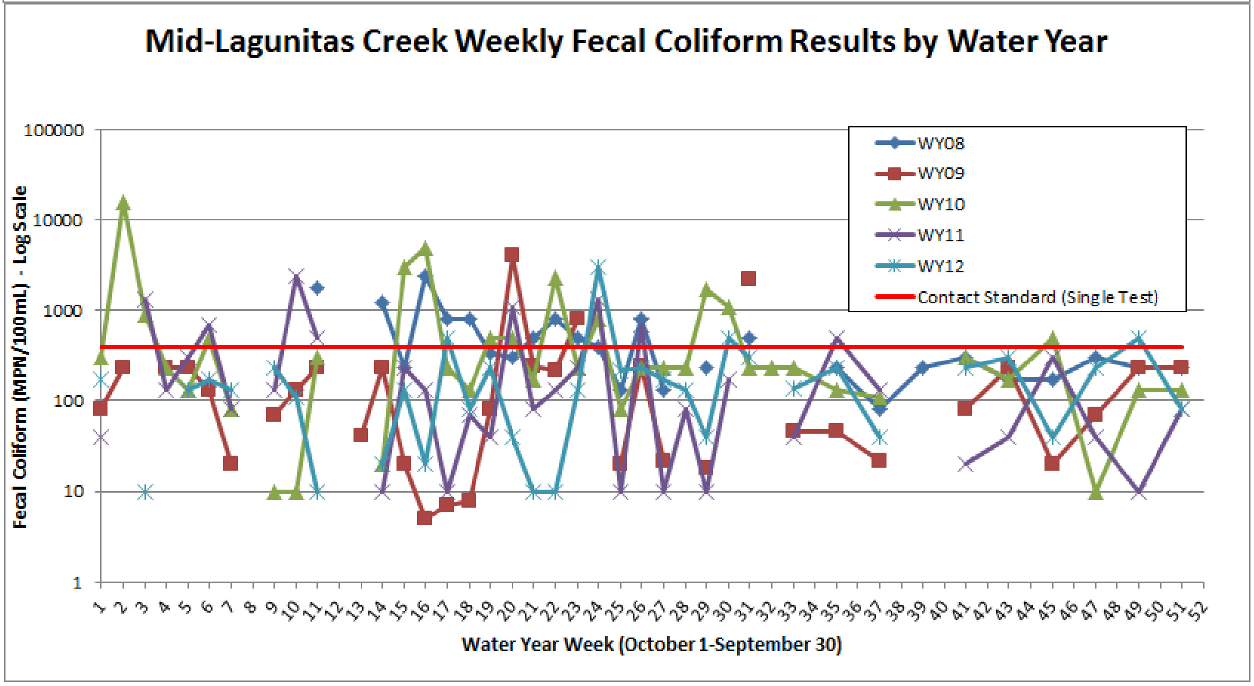

Mid-Bay Weekly Turbidity Results by Water Year
Turbidity (NTU)
0
2
4
6
8
10
12
Water Year Week (October 1-September 30)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
WY08
WY09
WY10
WY11
WY12

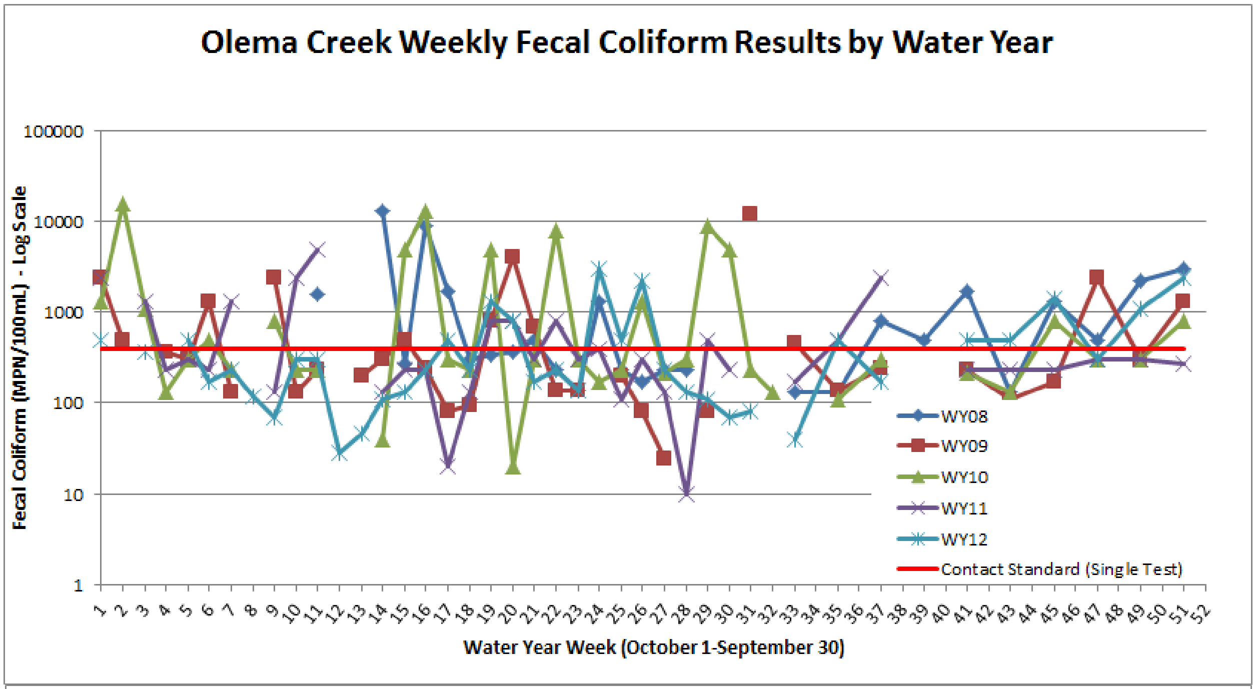

Outer Bay Weekly Turbidity Results by Water Year
Turbidity (NTU)
0
2
4
6
8
10
12
Water Year Week (October 1-September 30)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
WY08
WY09
WY10
WY11
WY12

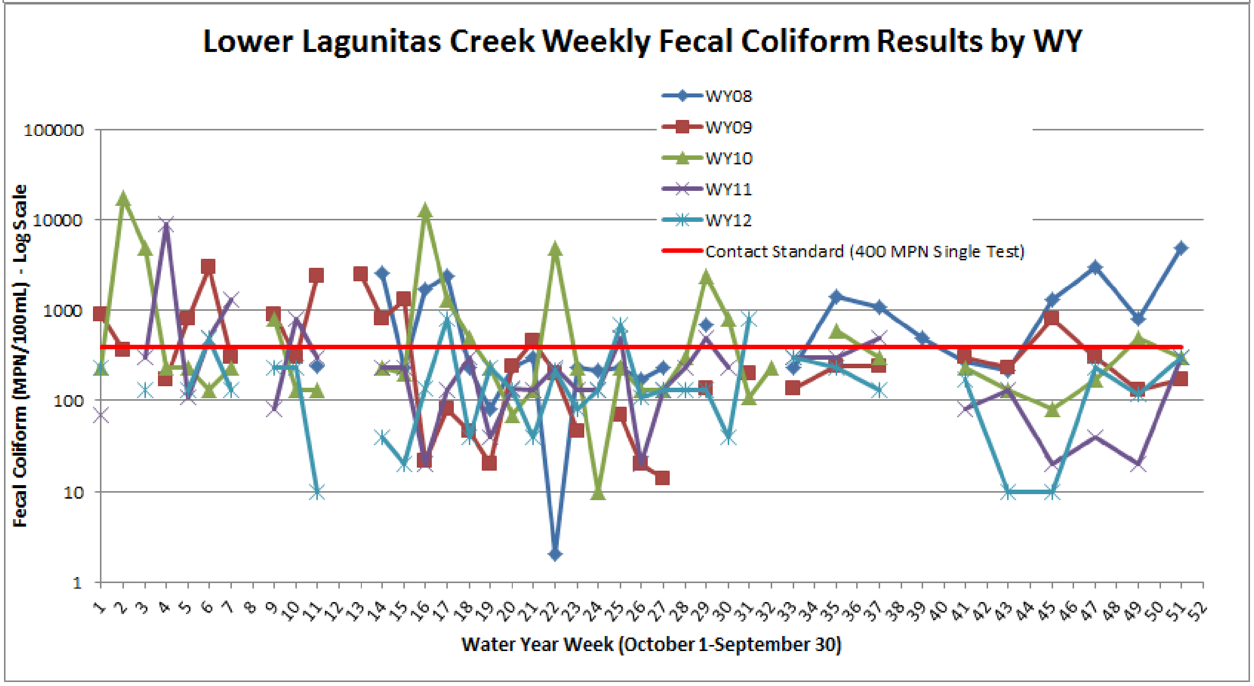
D. Fecal Coliform Bacteria Results

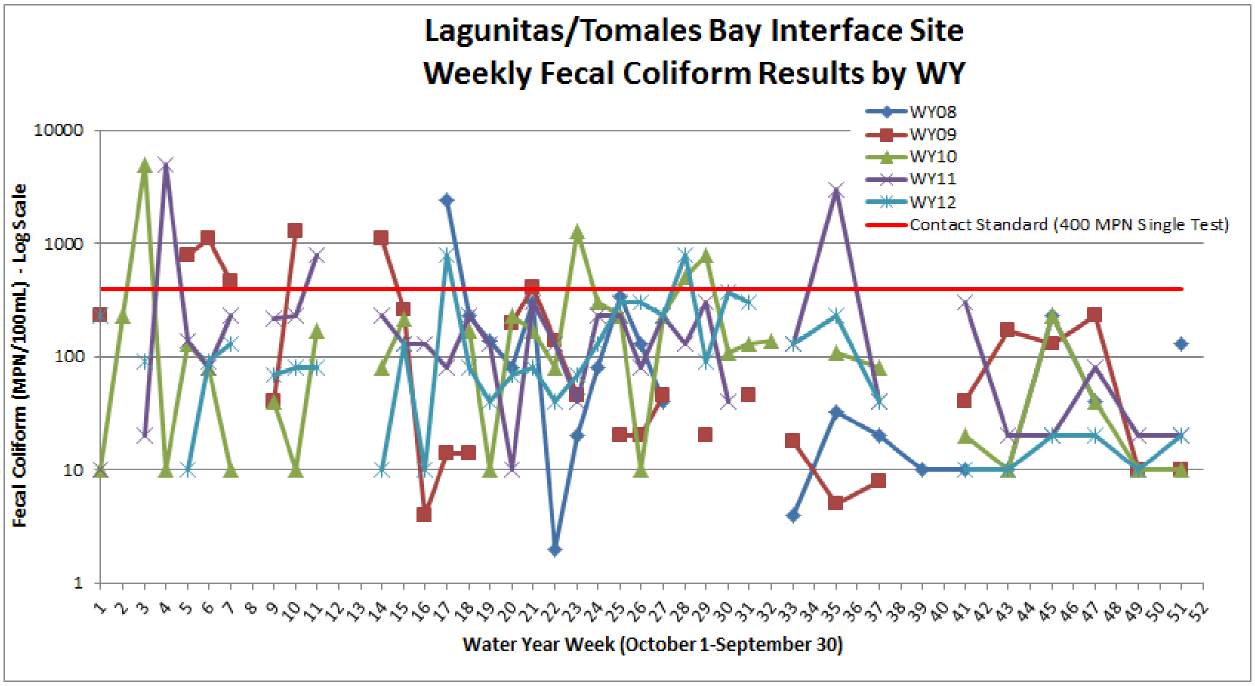
i. Lagunitas Creek Watershed Sites



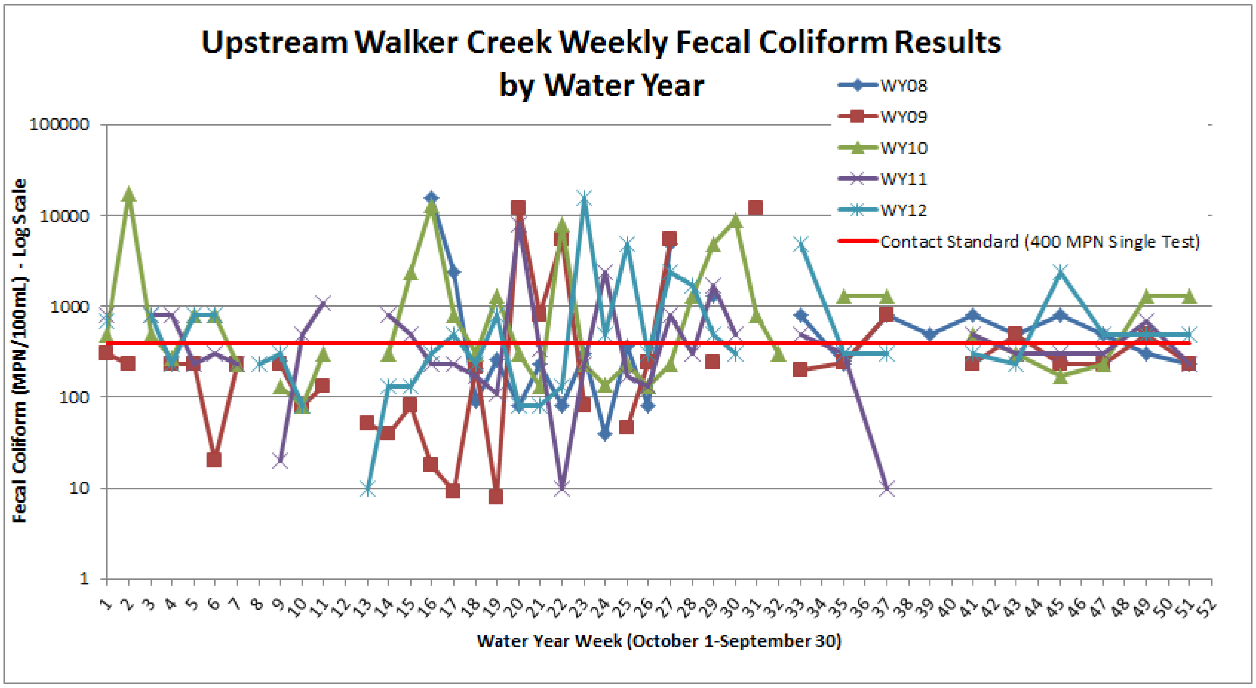


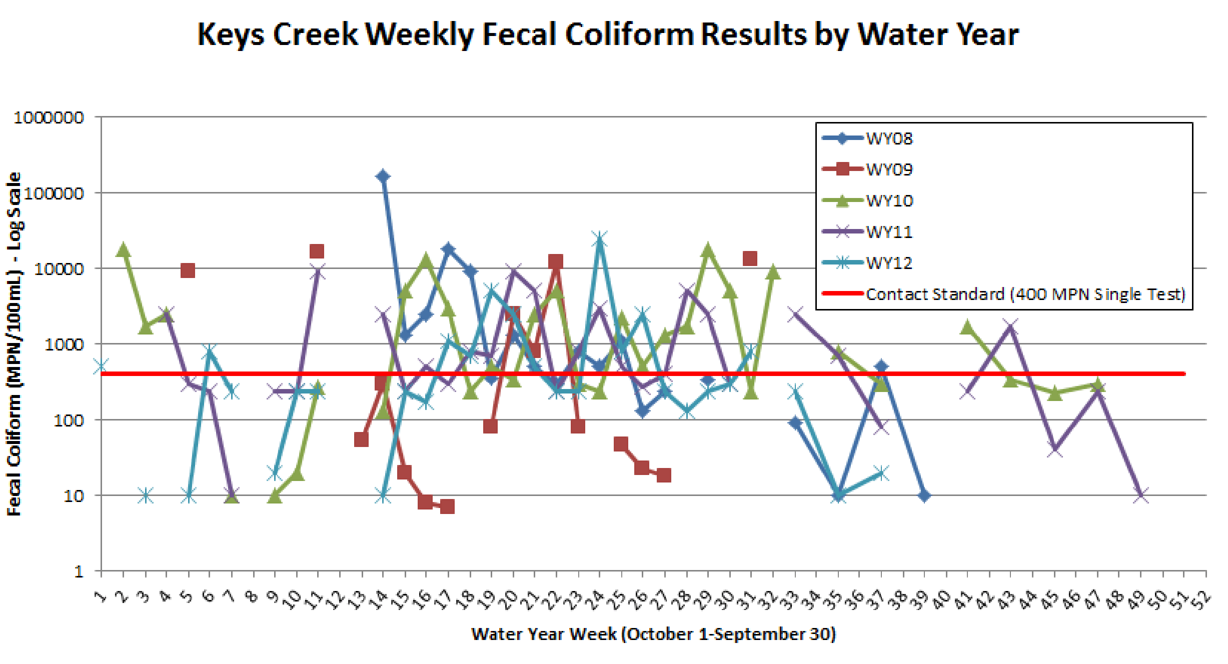

Olema Creek Weekly Fecal Coliform Results by Water Year
Fecal Coliform (MPN/100mL) - Log Scale
100000
10000
1000
100
10
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
Water Year Week (October 1-September 30)
WY08
WY09
WY10
WY11
WY12
Contact Standard (Single Test)

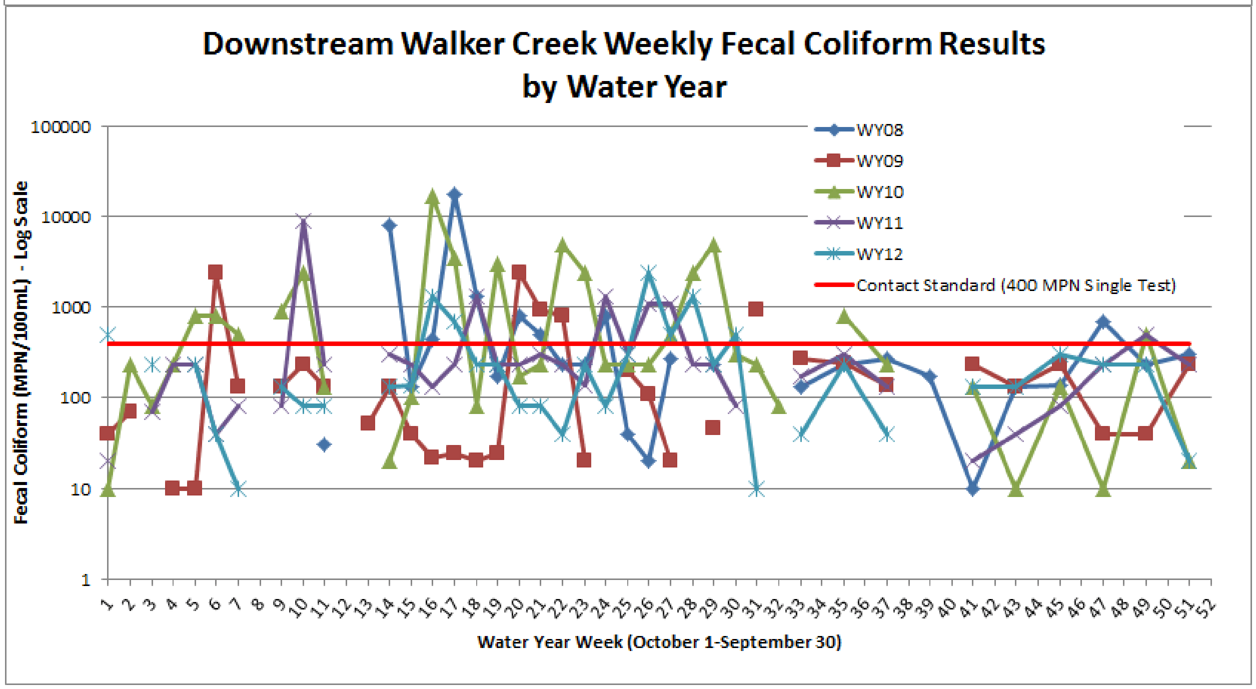

Lower Lagunitas Creek Weekly Fecal Coliform Results by WY
Fecal Coliform (MPN/100mL) - Log Scale
100000
10000
1000
100
10
1
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
Water Year Week (October 1-September 30)
WY08
WY09
WY10
WY11
WY12
Contact Standard (400 MPN Single Test)



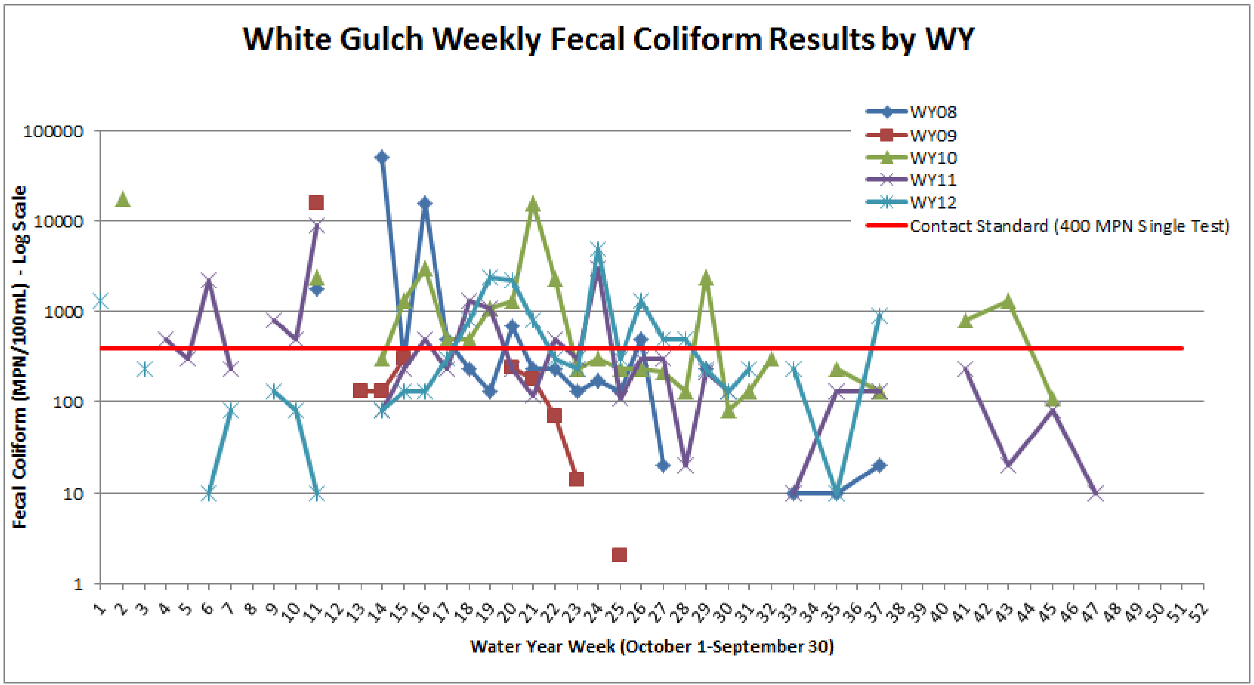
ii. Walker Creek Watershed Sites

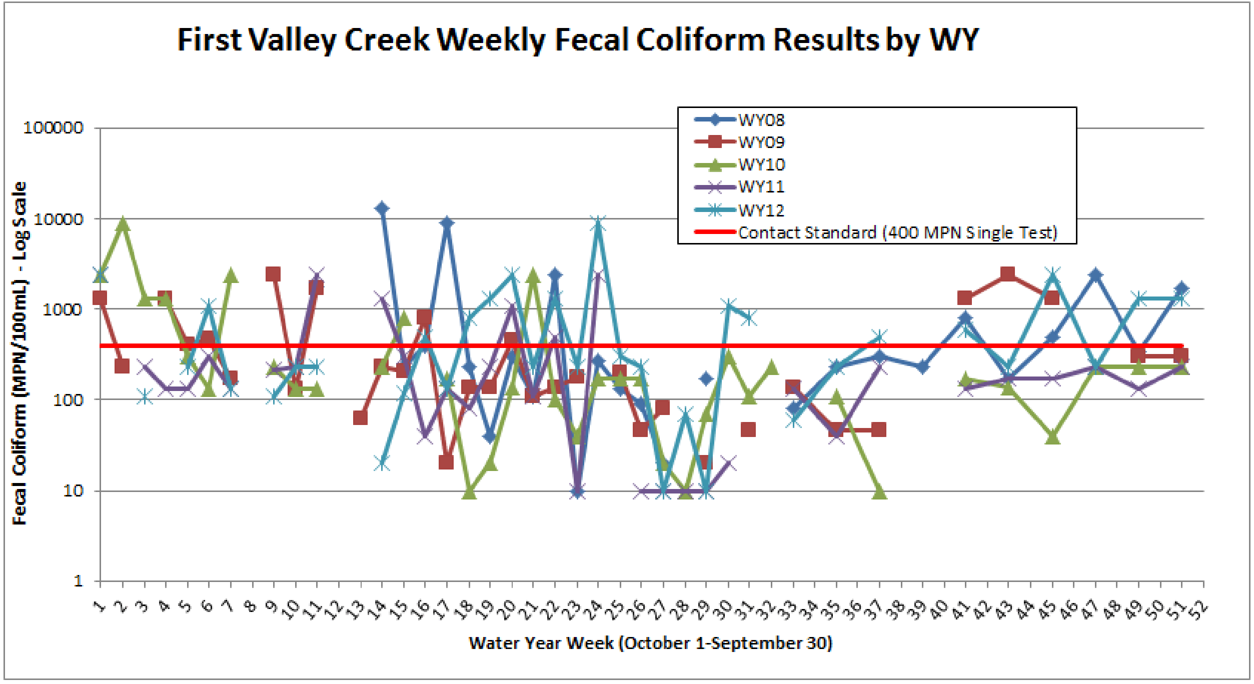


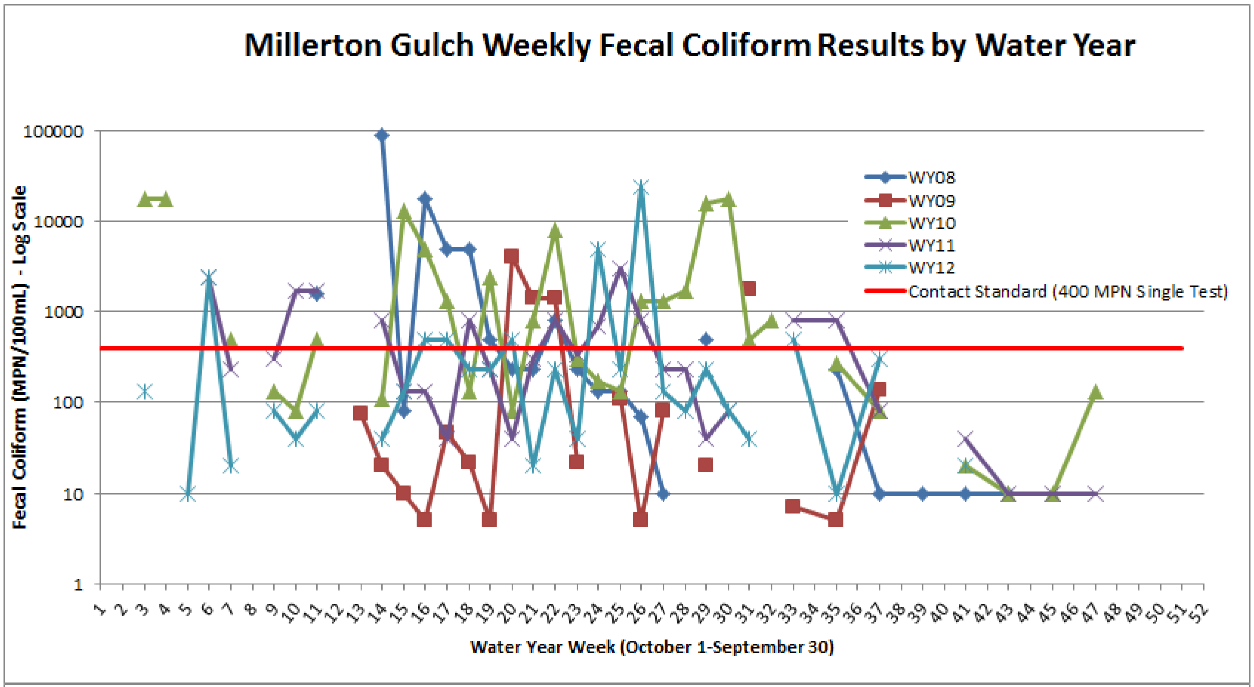

Keys Creek Weekly Fecal Coliform Results by Water Year
Fecal Coliform (MPN/100mL) - Log Scale
1000000
100000
10000
1000
100
10
1
Water Year Week (October 1-September 30)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
WY08
WY09
WY10
WY11
WY12
Contact Standard (400 MPN Single Test)


Downstream Walker Creek Weekly Fecal Coliform Results by Water Year
Fecal Coliform (MPN/100mL) - Log Scale
100000
10000
1000
100
10
1
Water Year Week (October 1-September 30)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
WY08
WY09
WY10
WY11
WY12
Contact Standard (400 MPN Single Test)

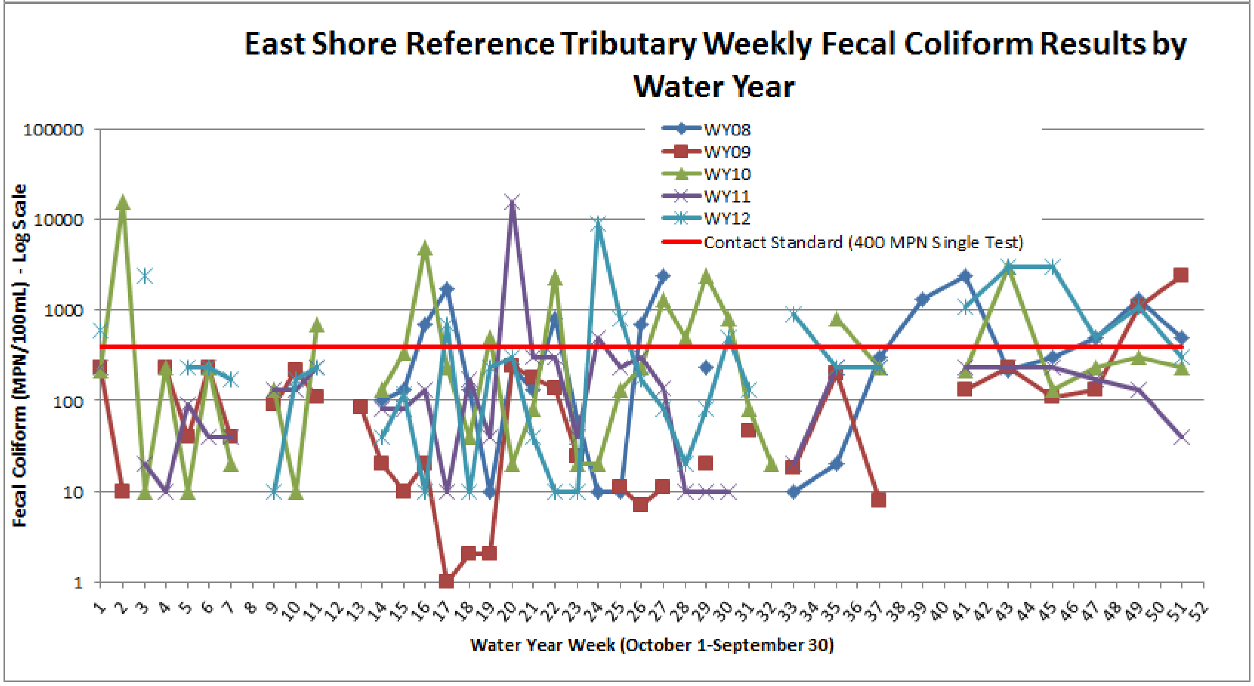
iii. Coastal Tributaries Watershed Sites





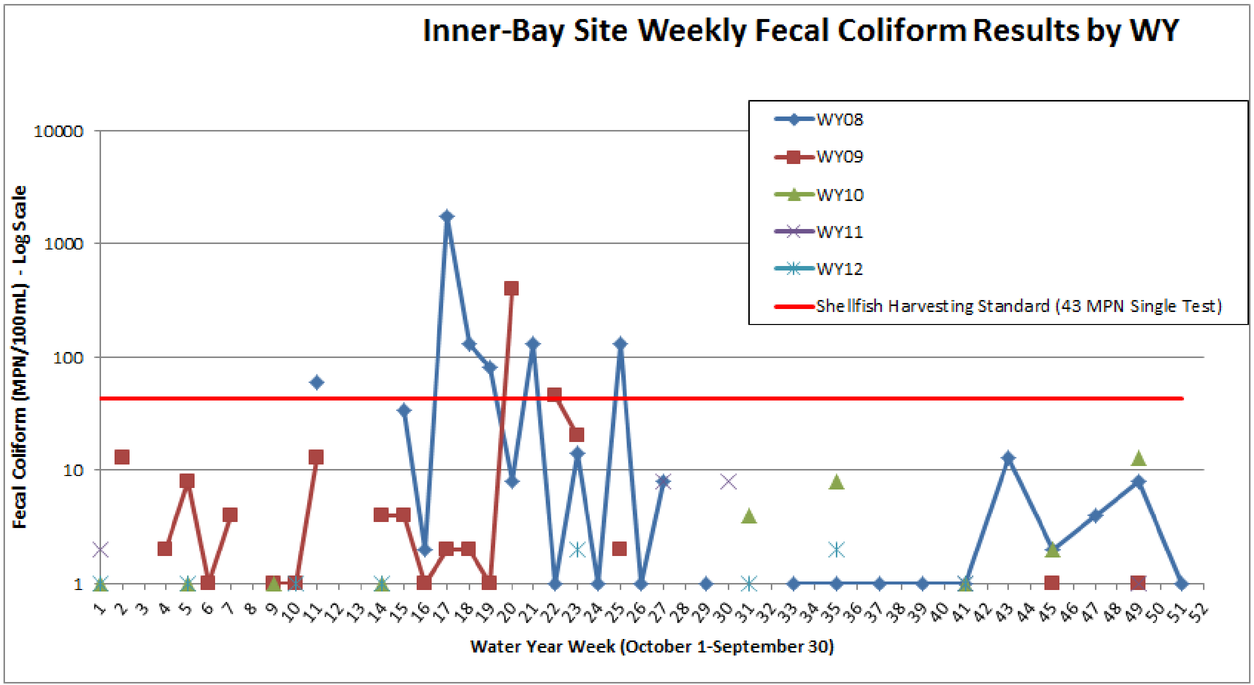


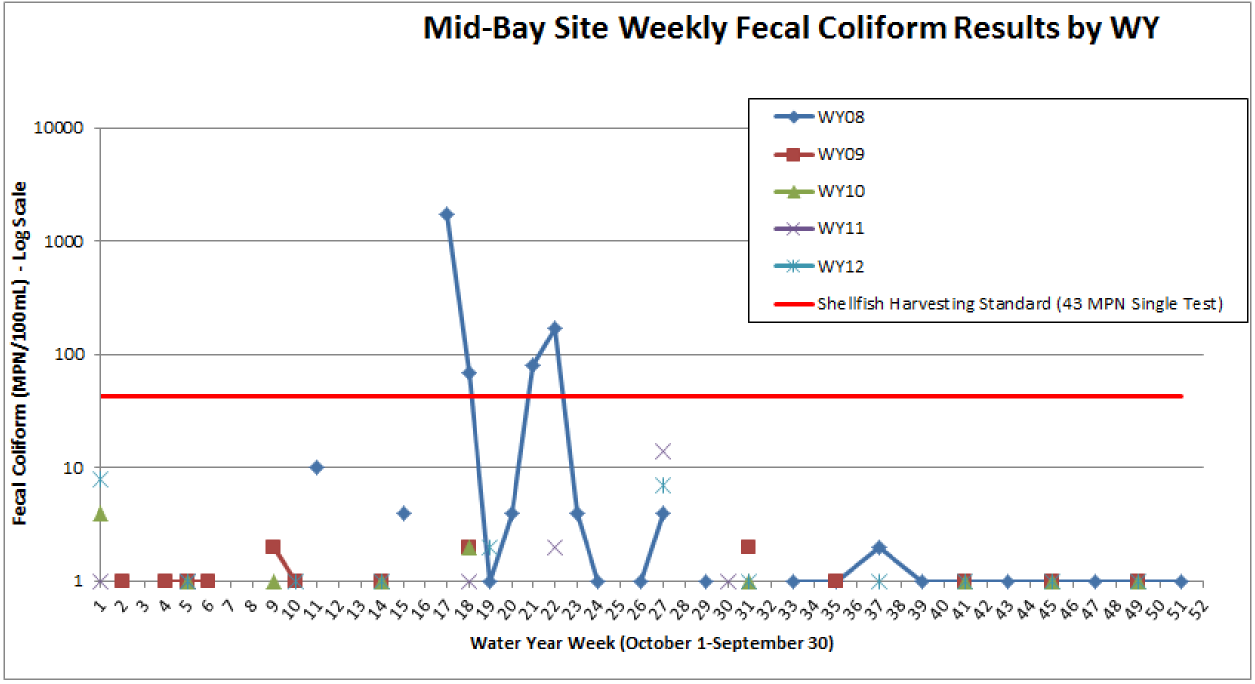
Millerton Gulch Weekly Fecal Coliform Results by Water Year
Fecal Coliform (MPN/100mL) - Log Scale
100000
10000
1000
100
10
1
Water Year Week (October 1-September 30)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
WY08
WY09
WY10
WY11
WY12
Contact Standard (400 MPN Single Test)

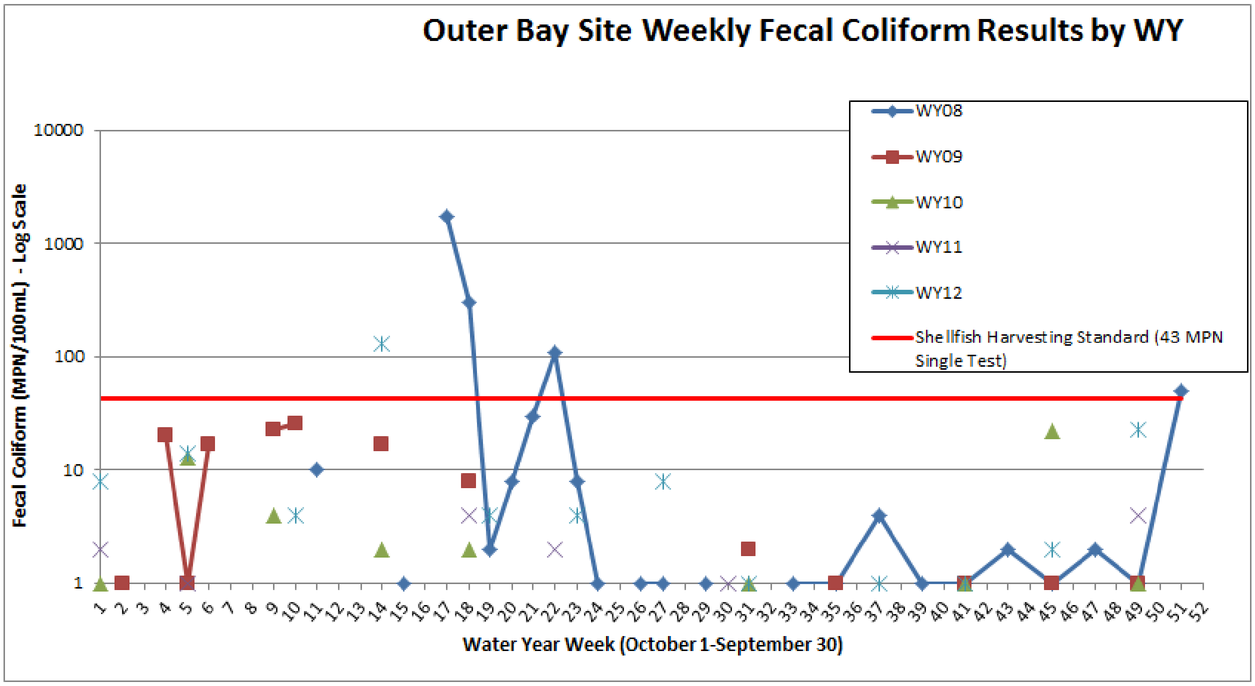


East Shore Reference Tributary Weekly Fecal Coliform Results by Water Year
Fecal Coliform (MPN/100mL) - Log Scale
100000
10000
1000
100
10
1
Water Year Week (October 1-September 30)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
WY08
WY09
WY10
WY11
WY12
Contact Standard (400 MPN Single Test)

iv. Tomales Bay Sites






Outer Bay Site Weekly Fecal Coliform Results by WY
Fecal Coliform (MPN/100 mL) - Log Scale
10000
1000
100
10
1
Water Year Week (October 1-September 30)
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52
WY08
WY09
WY10
WY11
WY12
Shellfish Harvesting Standard (43 MPN Single Test)

TBWC Final Technical Water Quality Report

Appendix E:

Legacy and Outside Group Water Quality Datasets and Status of Inclusion in TBWC Water Quality Database

Appendix E -

Legacy and Outside Group Water Quality Datasets & Status in TBWC WQ Database

Source	Project	Time Period	Stations	Sampling Area	Parameters	Data Status
Marin County Environmental Health Services	Recreational Use (Beach Program)	2003-2011	25 Sites at water contact recreation Sites in TB watershed, and Bolinas/Stinson Beaches; NOT all sites are sampled every year	Shore and Tributary recreation sites in TB watershed	E. coli; Fecal coliform; Total coliform; Enterococcus	**Complete - No known issues.** Data through 2010 entered in TBWC WQ database
CA Dept. of Fish & Game	MSCARII (Marin and Sonoma County Agricultural Runoff Influence Investigation)	1991-2002	21 sites, mostly downstream tributary sites on South and East Shore of Tomales Bay	Mostly bottom of tributaries to TB (South and East Shore)	pH; Temp; DO; Conductivity; NH3 total; HN3 toxic; Turbidity; BOD; Notes	**Incomplete, due to metadata issues.** Most data for stations T1-T19a entered in TBWC WQ database. Some sites not identified by GPS (possibly San Antonio watershed?); conductivity and BOD not entered due to unidentified units).

Source	Project	Time Period	Stations	Sampling Area	Parameters	Data Status
MMWD		1995-2002	Nicasio Crk.; Lag@ Nicasio; Soulajule Crk.; San Geronimo; Lag @ Kent (Shafter Bridge)	Upper LAG and Nicasio watershed	pH; Tem; Turbidity; Alkalinity; Hardness; Copper; TSS; Settleable solids	**Complete - No known issues.** Data entered in TBWC WQ database
NPS	TMDL and I&M and NOAA Fisheries BO	1995-Present	Olema Creek mainstem and tributary sites (6 TMDL; 2 NOAA Fisheris BO) ; 2-3 Lagunitas tributary sites (Cheda and Devil's Gulch)	Olema Creek watershed, some sites in mid and lower-Laguntias Creek	Field (pH; Cond; Salinity; Temp); TC/FC and E.coli; Nutrient and sediment data fro I&M Program	**Incomplete, to be entered in TBWC database.** Data in correct format (NPSTORET backup from NPS backend db), import not yet completed to TBWC WQ database.
TB Shellfish TAC	Investigation of Nonpoint Pollution Sources Impacting Shellfish Growing Areas in TB	1995-1996	41 Stations in watershed and Tomales Bay	Mostly Shoreline Tribs and Bay Sites	Fecal Coliform; Total Coliform; E. Coli and Enterococcus	**Complete - No known issues.** Data entered in TBWC WQ database

Source	Project	Time Period	Stations	Sampling Area	Parameters	Data Status
SFRWQCB	Pathogen TMDL	**Trib Sites:** 5-week series Winter and Summer from Jan. '04-March '11 (no Summer '07); **Bay Sites:** 5-week series 1/04; 6/06; 1/07…7-8/2008; 1/09	24 Tributary Sites; 7 Bay Sites (Not all time periods have Bay site data)	11 sites in San Geronimo and Lagunitas (see SPAWN, below); 6 sites in Olema (see NPS, above); 4 sites in Walker/Keys Creek; 3 west shore tribs.; 2 east shore tribs.	Fecal Coliform; Some NPS data also has Total Coliform and *E. coli*	**Incomplete, data not yet entered.** Data in spreadsheet form from RWQCB. Import not yet completed to TBWC WQ database.
SFRWQCB	Pathogen TMDL	**Trib Sites:** Monthly (1st Tues.): 1-6/2004; 1-4/2005; 8-9 & 11-12/2005; 1-12/2006 (No Aug.); 1-4/2007; 8, 10, 12/2008; 1-12/2009 (No Aug. or Oct.); 1-6/2010; 3-5/2011.	24 Tributary Sites	11 sites in San Geronimo and Lagunitas (see SPAWN, below); 6 sites in Olema (see NPS, above); 4 sites in Walker/Keys Creek; 3 west shore tribs.; 2 east shore tribs.	Fecal Coliform; Some NPS data also has Total Coliform and *E. coli*	**Incomplete, data not yet entered.** Data in spreadsheet form from RWQCB. Import not yet completed to TBWC WQ database.

Source	Project	Time Period	Stations	Sampling Area	Parameters	Data Status
SPAWN	Pathogen TMDL and SPAWN monitoring sites	7/2000-3/2002	7 TMDL sites in San Geronimo Crk watershed (E. and W. forks + mainstem Woodacre Crk; Upstream and downstream on San Geronimo Crk; Arroyo and Montezuma Crks; Laguntias at Tocaloma); Some spot data from Lagunitas downstream of Kent; Devil's Gulch; & Park Street in Woodacre.	San Geronimo Watershed and Mid-Lagunitas Creek watershed	Most data is Fecal Coliform; Some monitoring has Ammonia; TKN; NO3; NO2; Ortho Phophate; Total Phosphorus; MBAS; Chlorophyll; pH; water temp; DO; SC & Salinity.	**Complete - No known issues.** Data entered in TBWC WQ database
TBWC	Trends	12/2007-9/30/2011	11 Tributary Sites and 4 Bay Sites (Bay Site data sporatic during winter 2009-2011)	TB Watershed	Temp; pH; Conductivity; DO; Total Coliform; Fecal Coliform; NO3; TKN; NH3; Total Phosphorus; Turbidity; TSS; Discharge	**Complete - No known issues.** Data entered in TBWC WQ database

Source	Project	Time Period	Stations	Sampling Area	Parameters	Data Status
TBWC	Source Area	12/07-Present	Multiple sites in each target watershed.	Heart's Desire; San Geronimo Crk; Keys Creek; Olema Creek; Millerton Gulch; Tomasini Creek; 2nd & 3rd Valley Crks and Chicken Ranch Beach	Depending on target, may include: Temp; pH; Conductivity; DO; Total Coliform; Fecal Coliform; E. coli; NO3; TKN; NH3; Total Phosphorus; Turbidity; TSS; Discharge; Metals	**Complete - No known issues.** Data entered in TBWC WQ database
TBWC	Stormwater (Prop 50 I)	2006-2008	13 sites in Woodacre sotrmwater system; 3 Woodacre Crk. and San Geronimo Crk. sites; 10 sites in Point Reyes stormwater system, 1 site each in Lagunitas and Tomasini Crks.; 4 sites in Tomales stormwater system	Woodacre, Tomales and Pt. Reyes Stn. Stormwater systems;	Temp; pH; Conductivity; DO; Total Coliform; Fecal Coliform; E. coli; NO3; TKN; NH3; Total Phosphorus; Turbidity; TSS; Discharge; VOC's; Metals;	**Complete - No known issues.** Data entered in TBWC WQ database

Appendix F -
Source Area Monitoring Results WY10- WY12

This appendix contains reports of Source Area Program water quality monitoring results for targeted subwatersheds during the 2010, 2011 and 2012 water years (there was no Source Area monitoring during the 2009 water year). The results from the 2008 Source Area Program sampling were provided in the 2007-08 Annual Water Quality Report (Carson 2008) for the Program's previous grant funding. The information in this appendix is organized in the following sections:

I. Source Area Program Description

Source area monitoring efforts are focused on identifying sources and quantities of water pollutants to Tomales Bay and its freshwater tributaries. While Trend monitoring is dependent on long-term sampling at a suite of permanent sampling sites, source area monitoring is both flexible and responsive based on the data collected. The intent of source area monitoring is to support and prioritize future watershed or sub-watershed water quality improvement efforts, and to document conditions in order to evaluate the effectiveness of past efforts to improve water quality on private and public lands. This program builds on stormwater monitoring conducted in 2006 in the stormwater systems in the towns of Woodacre, Tomales and Point Reyes Station. More details on this project are detailed in a TBWC report (TBWC 2006).

Sampling sub-watersheds and sites are determined based upon the results of previous sampling and through prioritization of known source areas by the Water Quality Technical Advisory Committee (WQ TAC). Each winter of the program, one or two small subwatersheds were targeted for storm sampling. The target watersheds were divided into meaningful hydrologic units by selecting sites in particular reaches or at confluences within the constraints of public or privately-granted access. The sites were sampled during a significant rainfall event, and the results were used to characterize the patterns of pollutant levels in different parts of the subwatershed. After reviewing the results, site locations may be added, dropped or adjusted for the next storm sampling. Typically, 2-3 storm events in a winter were sampled for each of the targeted subwatersheds. Some adjustments were made over the course of the program based on identified priorities, program constraints and information gathered. The final two years of Source Area Program sampling (WY11 and WY12) focused on gathering pollutant level profiles during multiple storm events at a subset of our Trends Program sampling locations by sampling sites on multiple days during and after storm events.

II. Subwatershed Selection

Source Area Program subwatersheds were identified through discussions of the WQ TAC and in consultation with Council members and partners and the WQ Program Manager. During the first year (2007-08), monitoring of the rural stormwater sub-sheds continued, along with Heart's Desire State Park. The WQ TAC met regularly to prioritize Source Area watersheds and sampling protocol. Results of source area sampling are presented to WQ TAC members at regular meetings, and with involved groups in the prioritized areas where appropriate.

Data from source area sampling in the 2008 water year were detailed in the 2007-08 Annual Water Quality Report (Carson, 2008). Because the program funding was suspended due to the state financial crisis during the 2008-09 wet season, the source area element of the program was suspended before significant rainfall occurred. At a meeting in September 2009, the WQTAC decided that two of the sub-watersheds (Tomasini Creek and Keys Creek) that had been selected for 2009 should be sampled during the 2009-10 wet season. In addition, we would continue sampling on Third Valley Creek during storm events, and coordinate with the Salmon Protection and Watershed Network (SPAWN) to analyze data from samples on San Geronimo Creek. Results of this sampling were presented to the WQ TAC in April 2010.

The difficulty of accessing some sites in these sub-watersheds hampered our ability to collect sufficient data to define source areas in many of these small watersheds, although the sampling did provide snapshots of water quality conditions during storm events in segments of the watershed. Other program constraints were the timing of storms, the varying response of different watersheds to rain events, and coordination with analytical laboratories.

In order to improve the useful data coming out of the Source Area Program, the WQ TAC determined in 2010 that remaining Source Area Program funding would be used to target selected Trends sites in major watersheds with intensive storm sampling (i.e. rising, falling limb, 1, 2 and/or 3, 4, 5-days after a significant rain event) around 3-5 storm events each winter. The goal would be to gain an understanding not only of the magnitude and duration of pollutant loading in major contributing sub-watersheds, but also whether there are thresholds of precipitation that correspond to loading events, and whether there were differences between watersheds in their response. This methodology was implemented during the 2011 water-year, and took place at our Trends Program sites in the Millerton Gulch and San Geronimo, Olema and First Valley Creeks. The close spacing of storms during WY11 frustrated attempts to gather the latter (day3-5) samples, however differences between monitored watersheds were observed. Additionally, sites in the Walker Creek watershed were targeted for storm profiles during a single storm in WY11 and one storm in WY12.

See the individual watershed reports below for results and assessments of water quality data for the target subwatersheds.

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III. Watershed Reports

The following section contains individual subwatershed reports for Source Area Program water quality monitoring. Each watershed report contains a map of the sampling locations, a summary of water quality results and any conclusions reached through program data review.

Keys Creek Source Area Program Watershed Report

Summary

Keys Creek was identified by early Trends Program sampling as a subwatershed with elevated concentrations of monitored constituents (bacteria, sediment and nutrients) at the downstream end. This along with the small size of the subwatershed, public access to sites along the length of the creek, and past data from stormwater monitoring in the town of Tomales meant that Keys was identified as a good candidate for further focused monitoring of multiple subwatershed sites to better characterize the patterns of pollutant concentrations in the watershed. Sites were identified and some initial sampling occurred in April 2008 after a small storm (0.2-0.35"of precipitation). Three storms were targeted during WY10 including a storm with >0.75" of rain on 12/12/2009; a storm of 2.25"of rain on 1/20/2010 and a storm of 1.7"of rain on 4/11/10.

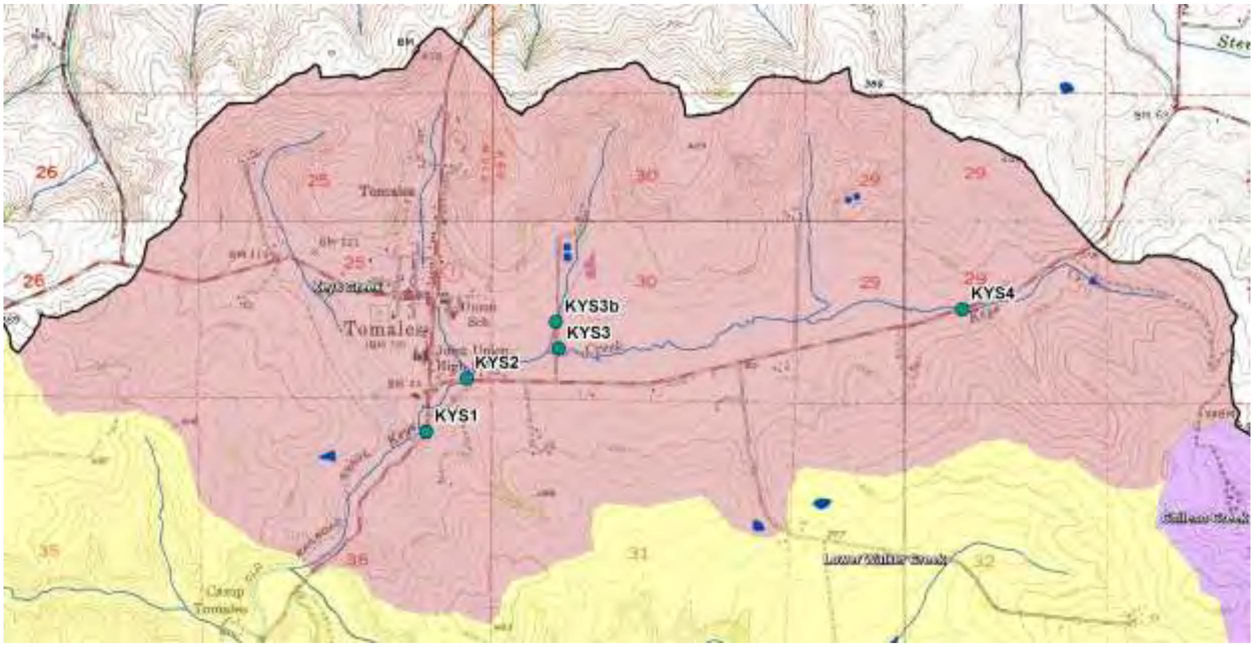
The same four sites (KYS1, KYS2, KYS3 and KYS4) were targeted for sampling on each event, with one sample from an additional site (KYS3b) on 4/11/10. The length of creek that is publicly accessible is short, and the four selected sites provided adequate segmentation of creek reaches. Not all sites were sampled during each event, depending on flow conditions. Measurements of field parameters (water temperature, Specific Conductance, salinity, dissolved oxygen and pH) were made after collecting lab samples from the site. Lab samples were analyzed for bacteria (Total coliform and *E. coli*), nutrients (Ammonia, nitrate, total Kjeldahl nitrogen, total phosphorus), and sediment (turbidity) according to the following summary table.

The most downstream site sampled in Keys creek (KYS1) is also one of the Trends Program long-term monitoring sites.

Sampling Events Summary

Sub-Watershed	Sampling Date	# of sampled Sites	Parameters
	4/23/2008[1]	3	[1]Bacteria and Field only
Keys Creek	12/12/2009[2]	3	
	1/20/2010[2]	4	
	4/11/2010[1]	5	[2]Bacteria, Nutrients, Sediment and Field (DO, pH, Temp., SC)

Keys Creek Source Area Sampling Site Map



Monitoring Results

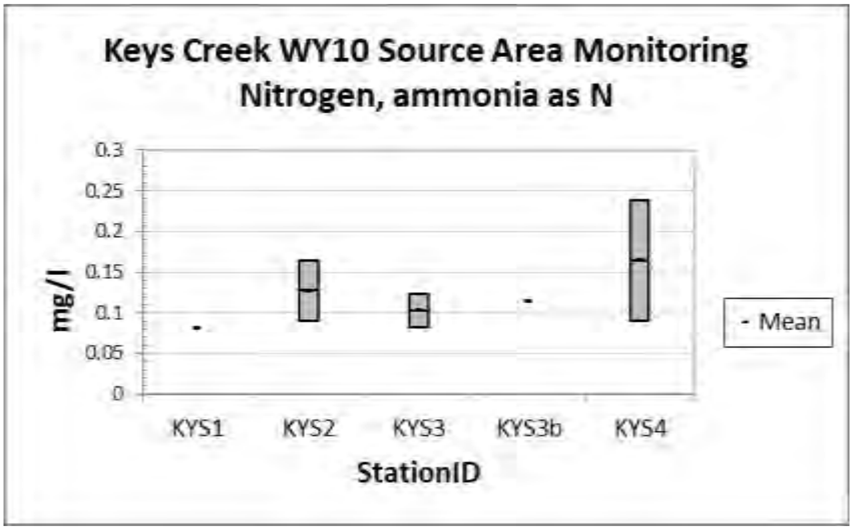
The section below details the range of results from the four sampling events at Source Area Program sites in Keys Creek. The tables below show the number of samples from each site that had quantifiable results for the parameter of interest. The figures below provide box graphs of the results for each parameter with maximum, minimum and mean indicated. If only one result was quantified for a site, the point is indicated on the graph by the mean symbol.

Censored results (i.e. non-detects) were excluded from the tables and graphs for nutrients and sediment, so the "# of samples" column in each table contains only the detected and quantified results. Censored results for bacteria parameters (i.e. non-detect or "present > quantification limit") were handled by substitution: using 0.5 * the lower quantification limit for non-detects and 1.1* the upper quantification limit for results over the test range.

Nutrients

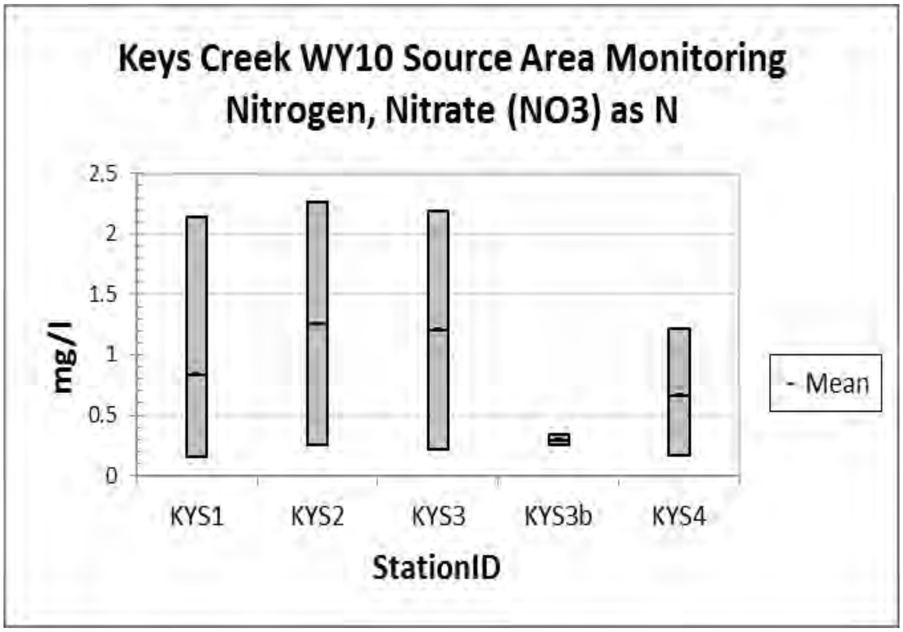
Ammonia

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
KYS1	12/12/2009-5/27/2010	2	0.0822	0.0822	0.0822
KYS2	12/12/2009-4/11/2010	2	0.0905	0.1645	0.1275
KYS3	12/12/2009-5/27/2010	2	0.0822	0.1234	0.1028
KYS3b	4/11/2010-5/27/2010	1	0.1151	0.1151	0.1151
KYS4	12/12/2009-5/27/2010	2	0.0905	0.2385	0.1645



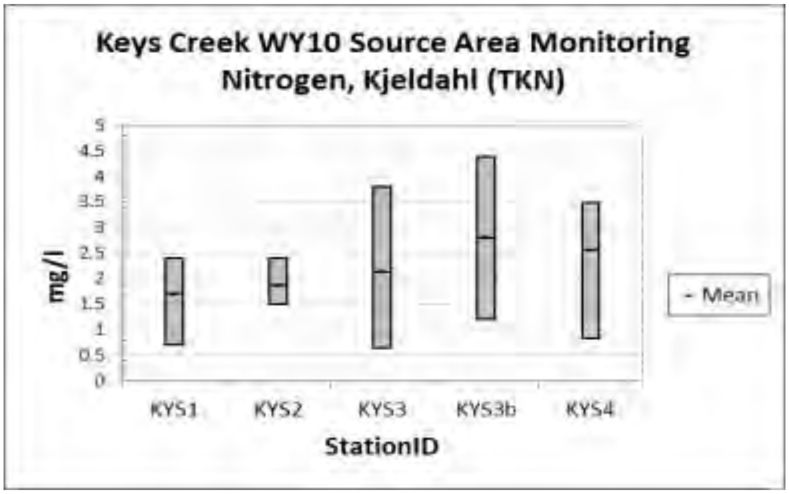
Nitrate

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
KYS1	12/12/2009-5/27/2010	3	0.1536	2.146	0.8388
KYS2	12/12/2009-4/11/2010	2	0.2485	2.259	1.254
KYS3	12/12/2009-5/27/2010	2	0.2214	2.191	1.206
KYS3b	4/11/2010-5/27/2010	2	0.2485	0.3388	0.2937
KYS4	12/12/2009-5/27/2010	3	0.1694	1.22	0.6664



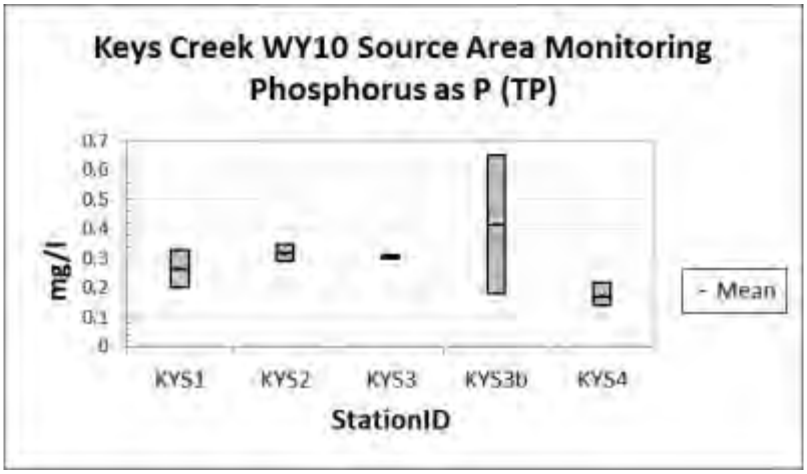
TKN

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
KYS1	12/12/2009-5/27/2010	4	0.71	2.4	1.703
KYS2	12/12/2009-4/11/2010	3	1.5	2.4	1.867
KYS3	12/12/2009-5/27/2010	4	0.65	3.8	2.138
KYS3b	4/11/2010-5/27/2010	2	1.2	4.4	2.8
KYS4	12/12/2009-5/27/2010	4	0.84	3.5	2.56



Total Phosphorus

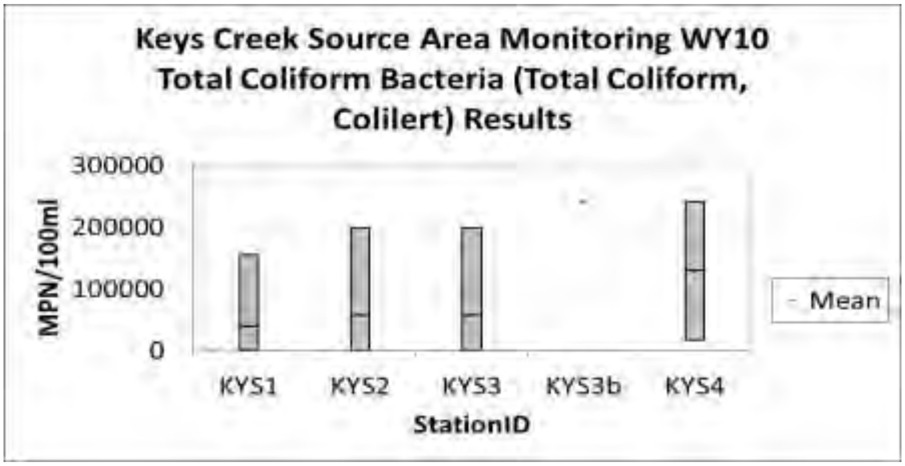
StationID	TimePeriod	# samples	Minimum	Maximum	Mean
KYS1	12/12/2009-5/27/2010	2	0.2	0.33	0.265
KYS2	12/12/2009-4/11/2010	2	0.29	0.35	0.32
KYS3	12/12/2009-5/27/2010	2	0.3	0.31	0.305
KYS3b	4/11/2010-5/27/2010	2	0.18	0.65	0.415
KYS4	12/12/2009-5/27/2010	3	0.14	0.22	0.17



Bacteria

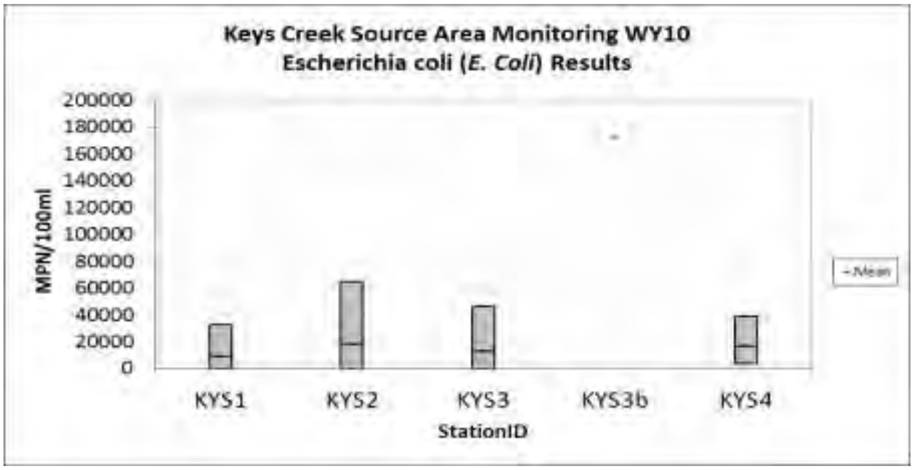
Total Coliform

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
KYS1	4/23/2008-4/11/2010	5	1,600	155,000	39,860
KYS2	4/23/2008-4/11/2010	4	560	199,000	57,415
KYS3	4/23/2008-4/11/2010	4	430	199,000	57,382
KYS3b	4/11/2010-4/11/2010	1	242,000	242,000	242,000
KYS4	12/12/2009-4/11/2010	3	17,000	242,000	129,667



E. coli

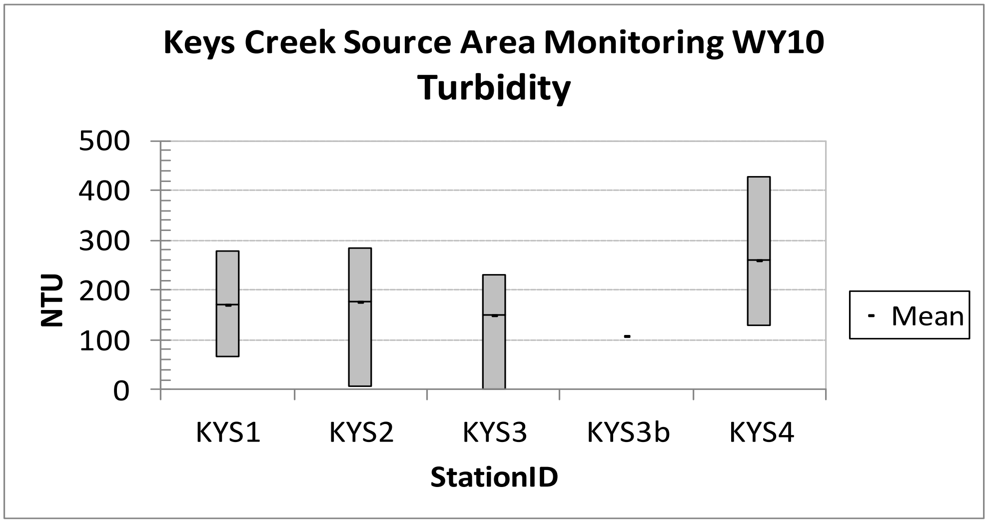
StationID	TimePeriod	# samples	Minimum	Maximum	Mean
KYS1	4/23/2008-4/11/2010	5	310	33000	9162
KYS2	4/23/2008-4/11/2010	4	200	65000	18325
KYS3	4/23/2008-4/11/2010	4	97	46000	12999
KYS3b	4/11/2010-4/11/2010	1	173000	173000	173000
KYS4	12/12/2009-4/11/2010	3	3600	39000	16800



Sediment

Turbidity

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
KYS1	1/20/2010-4/11/2010	2	65.2	278	171.6
KYS2	12/12/2009-4/11/2010	3	6.07	284	178
KYS3	12/12/2009-4/11/2010	3	1.72	231	150.6
KYS3b	4/11/2010-4/11/2010	1	108	108	108
KYS4	12/12/2009-4/11/2010	3	129	429	260.7



Discussion

The results of Source Area Program sampling in the Keys Creek watershed demonstrate that there are significant concentrations of nutrients, sediment and bacteria present across the watershed under storm conditions. The division of the watershed into three or four primary hydrologic units by the selected sampling locations did not provide clearer evidence of potential sources that would have warranted the selection of additional sites to narrow the focused search for sources. This is because elevated pollutant concentrations were observed both upstream and downstream of key infrastructure (town stormwater system, Tomales Village Community Services District facilities), and at the most upstream sampling location in the watershed. This suggests multiple sources of pollutant loading at many levels of the watershed. There is some evidence reflected in the data that pollutant concentrations decreased between KYS2 and KYS1, though this is likely due to a dilution factor resulting from inflow from vegetated ditches and runoff from the rural stormwater system for the town of Tomales rather than a reduction in pollutant loading. The sampling site KYS2, while publicly accessible, is located right at the confluence of Keys Creek and a small tributary carrying runoff from Tomales and may not be well mixed under all sampled conditions. Additional work with the public and private landowners in the watershed would be useful to identify or control potential sources and should be considered a priority focus area for improvement of water quality conditions.

Tomasini Creek Source Area Program Watershed Report

Summary

Tomasini Creek was identified by the WQ TAC in 2008 as a watershed with significant potential for impacts to the newly restored Giacomini wetlands. The fact that this small watershed was the most significant to pass through a portion of Pt. Reyes Station, the existence of past water quality data from the stormwater network in Pt. Reyes Station (Fall Creek Engineering 2007), and the ongoing monitoring at nearby sites by the NPS increased the potential value of this monitoring data. An additional potential impact that was identified was the closed West Marin Landfill in the middle reaches of Tomasini Creek. With these factors in mind, a plan was developed to conduct further focused monitoring of multiple subwatershed sites to better characterize the patterns of pollutant concentrations in the watershed.

Sampling took place during the 2009-10 winter season between December and April. Five storms were targeted during WY10 including a small storm of 0.2" of rain on 12/7/2009, a larger storm of 0.75"of rain on 12/12/2009, a major storm with 2.25" of rain on 1/20/2010; a storm of 1.0" of rain on 3/12/2010 and the tail end of a storm a storm of 1.8"of rain on 4/12/2010.

Five sites were sampled during WY10 storms. Two publicly accessible sites: the most downstream site (TOM1) at the Mesa Rd. crossing, and the site at the Highway 1 crossing (TOM4) were sampled during all five storms. At additional site midway between these (TOM2) was sampled twice (although the channel in this reach is meandering and braided and the sampled site may not be representative of the entirety of flow. An upstream site on Tomasini Crk. (TOM5) was sampled only during one event, and a tributary to Tomasini (TOM6) which joins the mainstem just before the Hwy. 1 crossing was sampled on two dates. An additional site in the watershed was identified later (TOMPIPE) and was the subject of sampling during the 2010-11 water year to characterize the quality of the discharge (the results of this monitoring can be found below). Additional sites were not targeted due to private property access constraints.

Measurements of field parameters (water temperature, Specific Conductance, salinity, dissolved oxygen and pH) were made after collecting lab samples from the site. Lab samples were analyzed for bacteria (Total coliform and *E. coli*), nutrients (Ammonia, nitrate, total Kjeldahl nitrogen, total phosphorus), and metals (cadmium, chromium, copper, silver, zinc and lead) according to the following summary table. See separate table of samples from TOMPIPE in the Source Identification and Characterization section below.

Sampling Events Summary

Sub-Watershed	Sampling Date	# of sampled Sites	Parameters
Tomasini Creek	12/7/2009	2	^{1}Bacteria, Nutrients & Sediment
	12/12/2009	2	^{2}Metals, Bacteria, Nutrients and Sediment
	1/20/2010	4	
	3/12/2010	3	
	4/12/2010	4	

Tomasini Creek Source Area Sampling Site Map

Monitoring Results

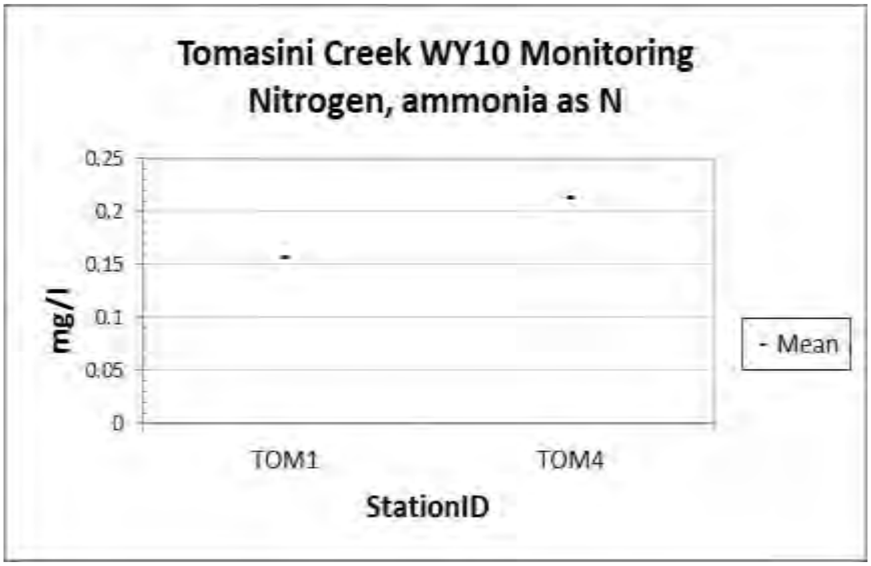
The section below details the range of results from the four sampling events at Source Area Program sites in Tomasini Creek. The tables below show the number of samples from each site that had quantifiable results for the parameter of interest. The figures below provide box graphs of the results for each parameter with maximum, minimum and mean indicated. If only one result was quantified for a site, the point is indicated on the graph by the mean symbol.

Censored results (i.e. non-detects) were excluded from the tables and graphs for metals, nutrients and sediment, so the "# of samples" column in each table contains only the detected and quantified results. Censored results for bacteria parameters (i.e. non-detect or "present > quantification limit") were handled by substitution: using 0.5 * the lower quantification limit for non-detects and 1.1* the upper quantification limit for results over the test range.

Nutrients

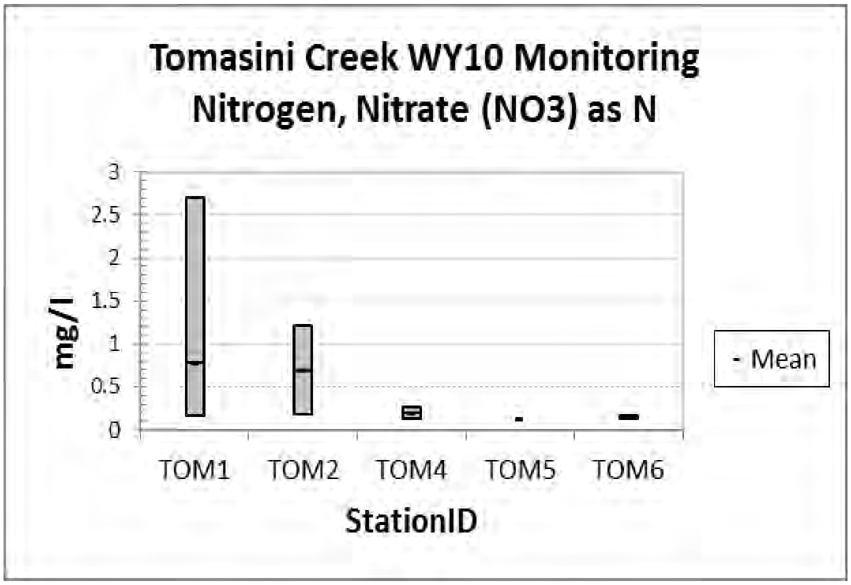
Ammonia

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
TOM1	12/7/2009-3/12/2010	1	0.1563	0.1563	0.1563
TOM4	12/7/2009-3/12/2010	1	0.2138	0.2138	0.2138



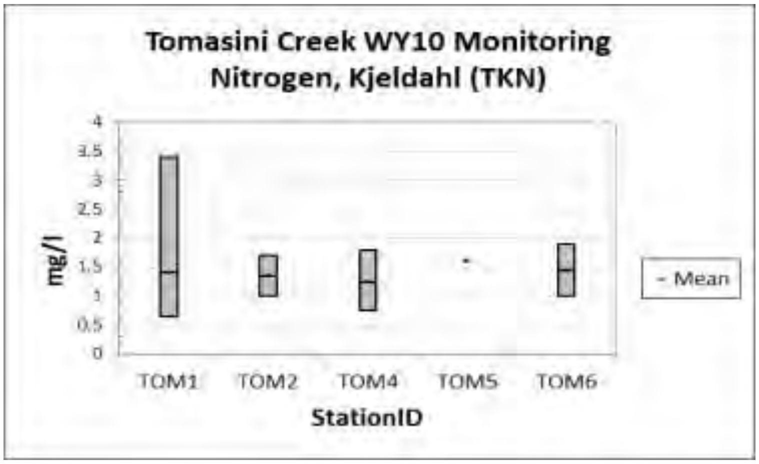
Nitrate

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
TOM1	12/7/2009-4/12/2010	5	0.1604	2.711	0.779
TOM2	1/20/2010-4/12/2010	2	0.1739	1.22	0.6969
TOM4	12/7/2009-4/12/2010	4	0.122	0.271	0.196
TOM5	1/20/2010-1/20/2010	1	0.1288	0.1288	0.1288
TOM6	3/12/2010-4/12/2010	2	0.122	0.1694	0.1457



TKN

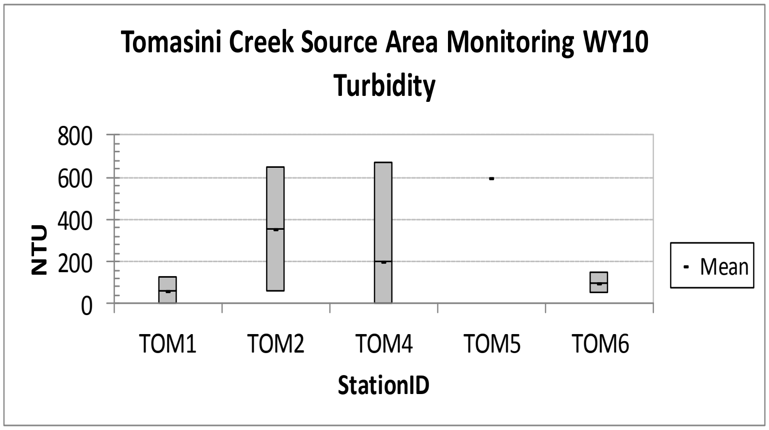
StationID	TimePeriod	# samples	Minimum	Maximum	Mean
TOM1	12/7/2009-4/12/2010	5	0.65	3.4	1.41
TOM2	1/20/2010-4/12/2010	2	1	1.7	1.35
TOM4	12/7/2009-4/12/2010	5	0.76	1.8	1.24
TOM5	1/20/2010-1/20/2010	1	1.6	1.6	1.6
TOM6	3/12/2010-4/12/2010	2	1	1.9	1.45



Sediment

Turbidity

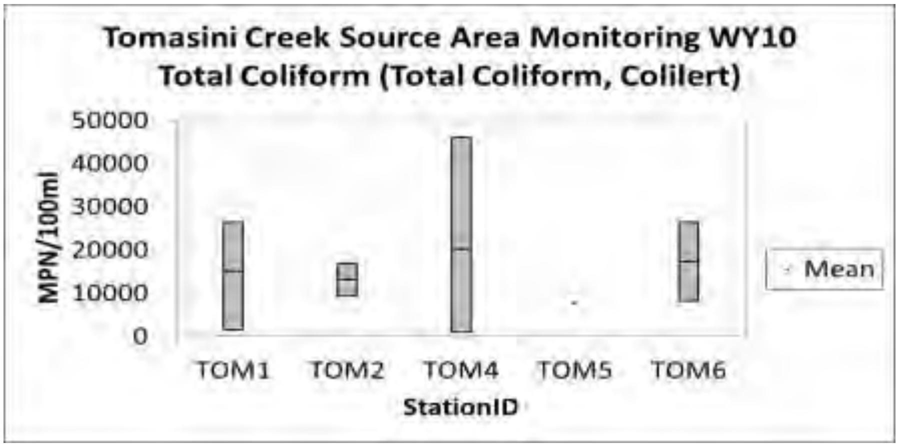
StationID	TimePeriod	# samples	Minimum	Maximum	Mean
TOM1	12/7/2009-4/12/2010	4	2.48	124	58.57
TOM2	1/20/2010-4/12/2010	2	61.3	647	354.2
TOM4	12/7/2009-4/12/2010	5	1.31	670	204.4
TOM5	1/20/2010-1/20/2010	1	594	594	594
TOM6	3/12/2010-4/12/2010	2	53.7	146	99.85



Bacteria

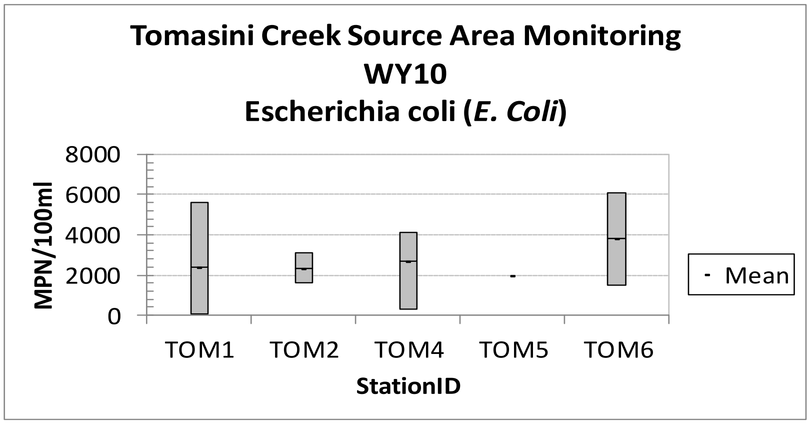
Total Coliform

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
TOM1	12/7/2009-4/12/2010	5	1,400	26,400	15,140
TOM2	1/20/2010-4/12/2010	2	9,300	17,000	13,150
TOM4	12/7/2009-4/12/2010	5	930	46,000	20,266
TOM5	1/20/2010-1/20/2010	1	7,700	7,700	7,700
TOM6	3/12/2010-4/12/2010	2	8,300	26,400	17,350



E. coli

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
TOM1	12/7/2009-4/12/2010	5	86	5,600	2,397
TOM2	1/20/2010-4/12/2010	2	1,600	3,100	2,350
TOM4	12/7/2009-4/12/2010	5	290	4,100	2,718
TOM5	1/20/2010-1/20/2010	1	2,000	2,000	2,000
TOM6	3/12/2010-4/12/2010	2	1,500	6,100	3,800

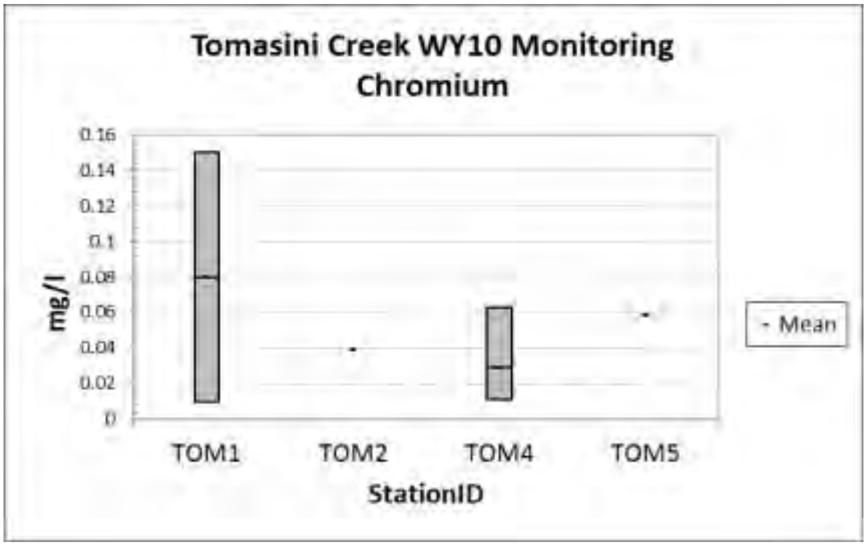


Metals

Cadmium(Cd) – No detections in any samples (<0.005 mg/L)

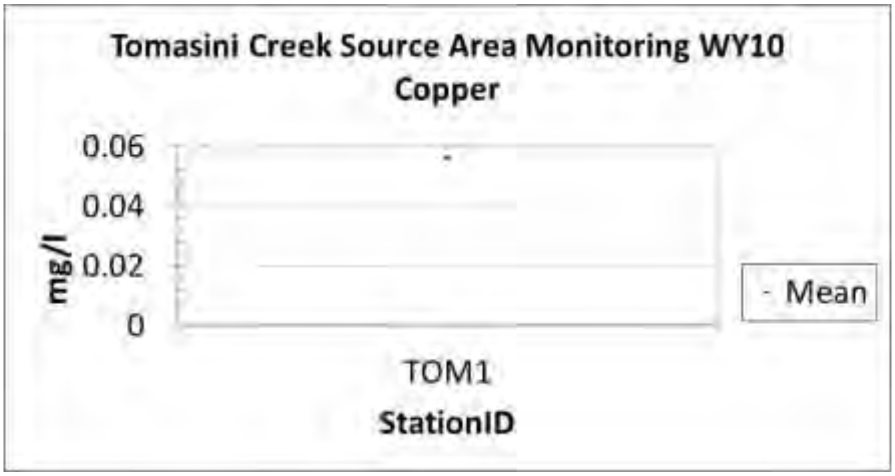
Chromium(Cr)

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
TOM1	12/12/2009-4/12/2010	2	0.01	0.15	0.08
TOM2	1/20/2010-4/12/2010	1	0.039	0.039	0.039
TOM4	12/12/2009-4/12/2010	3	0.011	0.063	0.029
TOM5	1/20/2010-1/20/2010	1	0.059	0.059	0.059



Copper (Cu)

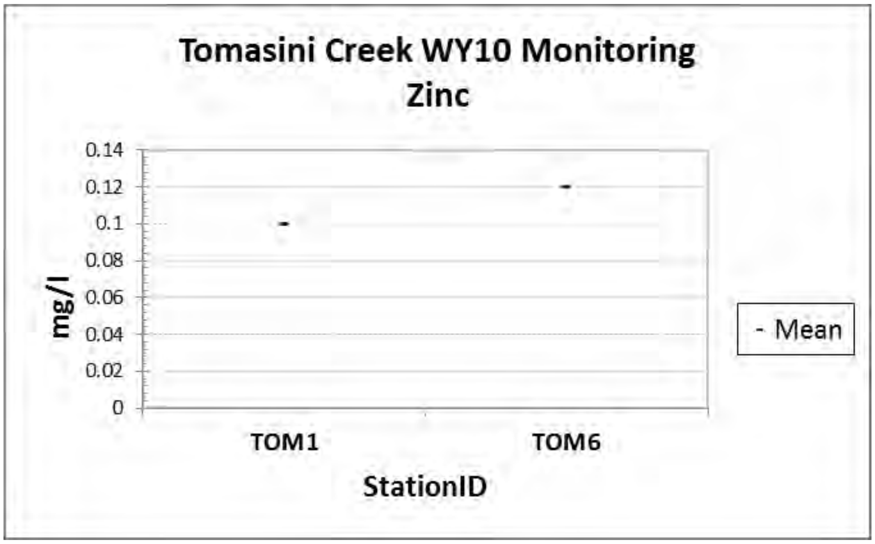
StationID	TimePeriod	# samples	Minimum	Maximum	Mean
TOM1	12/12/2009-3/12/2010	1	0.056	0.056	0.056



Silver (Ag) – No detections in any samples (<0.01 mg/L)

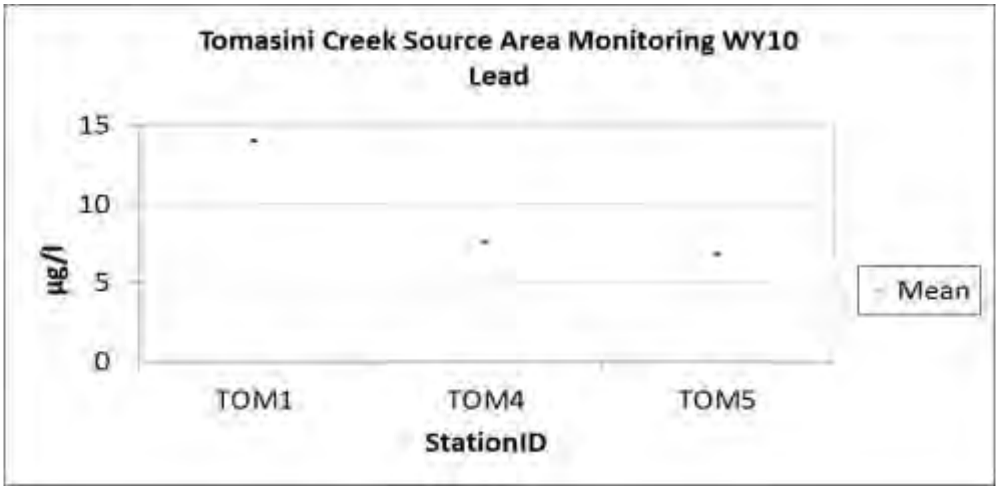
Zinc (Zn)

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
TOM1	12/12/2009-4/12/2010	1	0.1	0.1	0.1
TOM6	3/12/2010-4/12/2010	1	0.12	0.12	0.12



Lead (Pb)

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
TOM1	12/12/2009-3/12/2010	1	14	14	14
TOM4	12/12/2009-3/12/2010	1	7.6	7.6	7.6
TOM5	1/20/2010-1/20/2010	1	6.8	6.8	6.8



Source Identification and Characterization

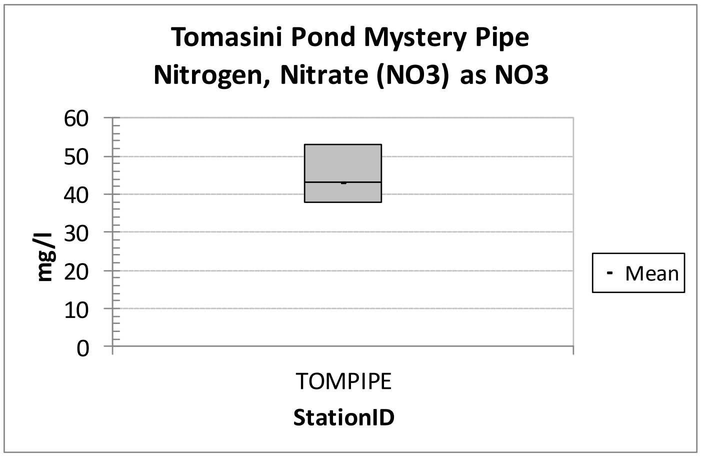
After our project partner, the National Park Service, reported elevated levels of nutrients in the vicinity of Tomasini Pond during scheduled monitoring of the larger wetland restoration project area, site reconnaissance revealed the presence of a 6” PVC pipe of unknown origin which was flowing in late summer. TBWC Program staff sampled the pipe on several occasions analyzing the water samples to help characterize its quality and determine its source.

Sub-Watershed	Sampling Date	# of sampled Sites	Parameters
Tomasini Pond Mystery Pipe	8/30/2010	1[1]	[1]Nutrients, Bacteria and MBAS
	9/9/2010	1[2]	[2]Nutrients and Bacteria only
	9/21/2010	1[1,3]	[3]Trihalomethanes (THMs)
	1/12/2011	1[2]	

Initially, the water was tested for bacteria, nutrients and MBAS. The latter being a marker of detergents or surfactants which could be symptomatic of the involvement of septic systems. Results showed low, but detectable levels of MBAS (0.007-0.016 mg/L) in samples from the pipe. Bacteria testing showed very low levels of fecal coliform and *E. coli* discharging from the pipe, so serious involvement of failing septic systems was determined to be unlikely.

Because the pipe was flowing at about 175mL/second at the end of the summer season, we suspected the possible involvement of a drinking water supply line, so we also tested one set of samples for Trihalomethanes which are markers of the byproducts of chlorination. There were no detections for THMs, so the source of the flow was determined unlikely to be drinking water supply. There are shallow groundwater lenses on the mesa which may be the most likely source of flow to the pipe during dry weather (L. Parsons, pers. comm).

The results of nutrient tests on the water from the pipe revealed a serious and persistent source of nitrogen loading. While levels of ammonia were not detectable and organic nitrogen (TKN) levels were low, levels of nitrate were <u>extremely</u> elevated (between 38 mg/L and 53 mg/L nitrate as NO_3) during <u>all</u> sampling events. This suggests a persistent source of nitrogen pollution was being carried by the pipe from its unknown origin to the Tomasini Pond area. The graph below shows the range of nitrate results from the four samples, expressed as mg/L of Nitrate as $N0_3$.



Discussion

The results of Source Area Program sampling in the Tomasini Creek watershed demonstrate that there are elevated concentrations of nutrients, sediment and bacteria present across the watershed under storm conditions, although at fairly typical levels found in other nearby watersheds. There is a pattern of increased loading between our upstream sites (TOM6, TOM5 and TOM4 and the most downstream site (TOM1) suggesting that, under storm conditions, there are sources loading to the stream downstream of the Highway 1 crossing. This area is rural residential with houses and some horses. It should be noted that not all sites were sampled during every event, so minor differences in mean concentrations between sites reported in the tables above may reflect unpaired samples. The one exception to this pattern appeared to be turbidity, with lower levels measured at the downstream culvert. The topography of the lower reaches of Tomasini Creek (from upstream of TOM2 to TOM1) are marked by a low-gradient, wandering channel through willows that appears to be encouraging sediment deposition.

The metals analyses resulted in detections of copper (Cu) and zinc (Zn) at the downstream site (TOM1), and of chromium (Cr) and lead (Pb) both at upstream and downstream sites. Again, where detected at both upstream and downstream sites, the levels of metals were more elevated at the downstream site, which is troubling because of the corresponding increase to loading rates. Although, it should be noted that the results of metals analysis showed similar, relatively low, levels to those measured at storm drain network sites in the town of Pt. Reyes Station during previous monitoring efforts (Fall Creek Engineering 2007).

Public access is difficult in this watershed and so, therefore, is identifying source areas. Given the direct influence of this watershed on the restored Giacomini wetlands, additional monitoring of this drainage should be considered important to assess any downstream impacts.

One partial success that our source area monitoring had was the identification and characterization of a significant source of nitrate input to the Tomasini Pond through the "mystery pipe". The ultimate source of this pollution is not entirely clear, but it may be a remnant of the site drainage plan put in with the development of a small subdivision at the end of B Street. A meeting in early 2011with program staff, a representative of the RWQCB and private landowners revealed the possible historic presence of a chicken farm on the site of a current senior housing complex on B Street between 6th and 7th Street. A legacy of chicken waste in the soil at the site, a notoriously long-lasting source of nitrates, may be responsible for the continued high levels detected at the end of the mystery pipe. The pipe is likely tapping into shallow groundwater sources on the mesa and carrying the nitrates through to Tomasini Pond. This issue remains unresolved, but should be considered a priority given the extreme levels of nutrient loading occurring year-round at the site, and the potential impact of the discharge on downstream habitat and sensitive species.

San Geronimo Creek Source Area Program Watershed Report

Summary

San Geronimo Creek was identified by early Trends Program sampling as a subwatershed with elevated concentrations of monitored constituents at the downstream end. This along with significant past monitoring data from the RWQCB pathogen TMDL and from SPAWN in the subwatershed, public access to sites along the length of the creek, and additional past data from stormwater monitoring in the town of Woodacre meant that San Geronimo was identified as a good candidate for further focused monitoring of multiple subwatershed sites to better characterize the patterns of pollutant concentrations in the watershed. SPAWN staff and volunteer collected samples from established sites across the watershed. This program provided the laboratory and data analysis of project results.

Sampling took place during the 2009-10 winter season between October and January. Three storms were targeted during WY10 including a major storm with 4.6” of rain on 10/13/2009; a storm of 0.75” of rain on 12/12/2009 and a storm of 1.6”of rain on 1/19/2010.

Five sites were sampled during all three storms. From upstream to downstream, the sites were Park St (E. Fork Woodacre Creek), WS19 (Woodacre Creek), WS20 (San Geronimo at Roy’s Pools), WS21 (Montezuma), WS22 (Arroyo). Additional sites (SG1 and WS23 (Inkwells)) were sampled during the latter two storm events.

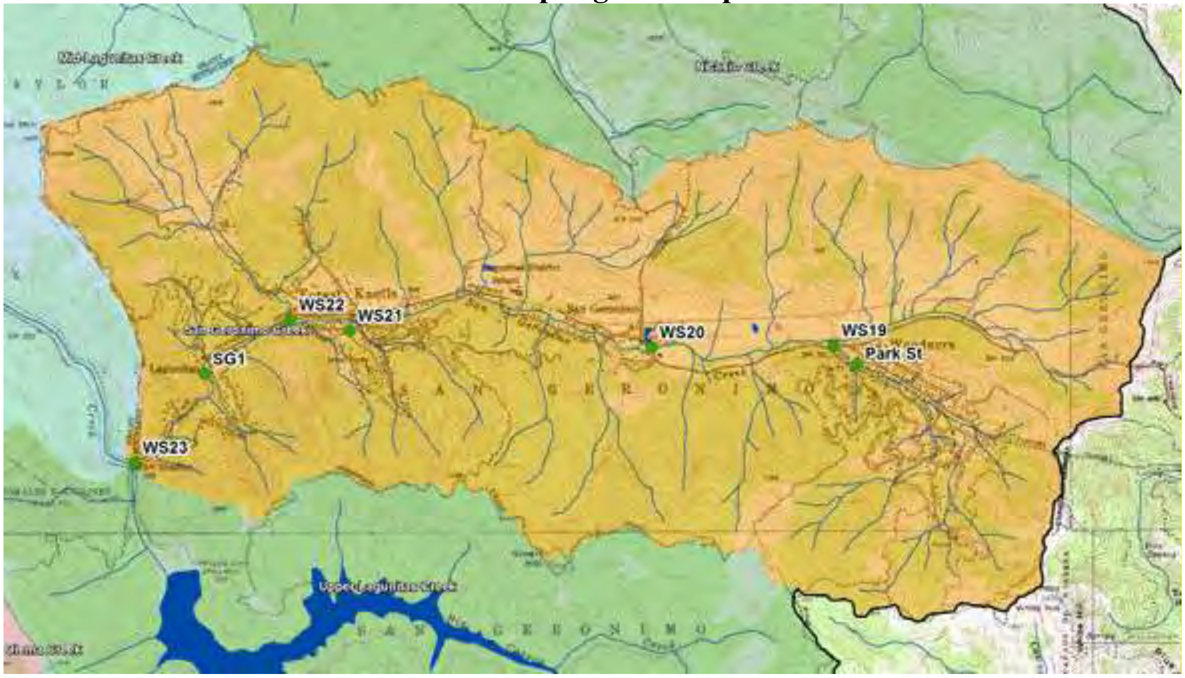
Measurements of field parameters (water temperature, Specific Conductance, salinity, dissolved oxygen and pH) were made after collecting lab samples from the site. Lab samples were analyzed for bacteria (Total coliform and *E. coli*), nutrients (Ammonia, nitrate, total Kjeldahl nitrogen, total phosphorus), metals (cadmium, chromium, copper, silver, zinc and lead) and MBAS (Methylene Blue Active Substances, a test for detergents or surfactants) according to the following summary table.

These sites have been sampled extensively by the RWQCB through their pathogen TMDL, and by SPAWN through independent efforts to characterize water quality in the watershed. In addition, the storm drain network and creeks in Woodacre were the subject of intensive storm sampling by the TBWC in 2006-08 (Fall Creek Engineering 2007).

Sampling Events Summary

Sub-Watershed	Sampling Date	# of Sites	Parameters
San Geronimo Valley	10/13/2009	$5^{1,2}$	^{1}Bacteria and Nutrients
	12/12/2009	$7^{1,3}$	^{2}MBAS
	1/19/2010	7^{1}	^{3}Metals

San Geronimo Creek Source Area Sampling Site Map



Monitoring Results

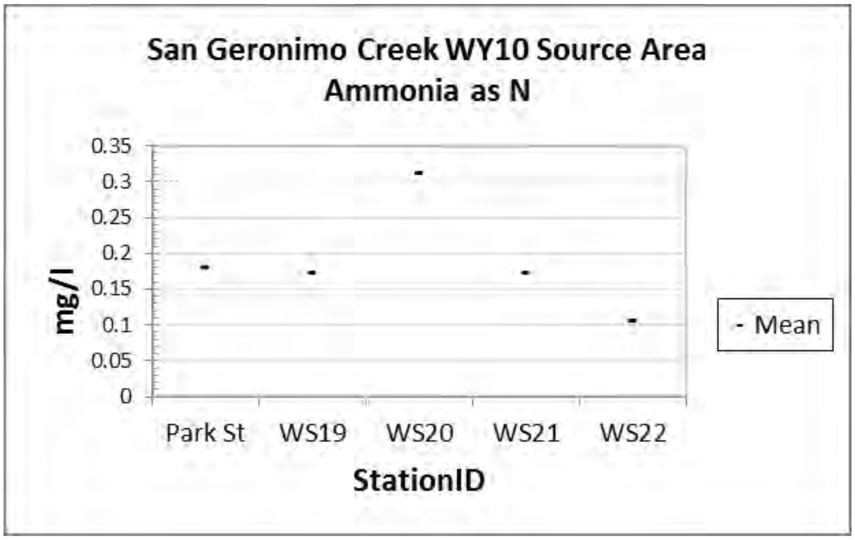
The section below details the range of results from the four sampling events at Source Area Program sites in San Geronimo Creek during WY10. The tables below show the number of samples from each site that had quantifiable results for the parameter of interest. The figures below provide box graphs of the results for each parameter with minimum, maximum and mean indicated. If only one result was quantified for a site, the point is indicated on the graph by the mean symbol.

Censored results (i.e. non-detects) were excluded from the tables and graphs for nutrients and sediment, so the "# of samples" column in each table contains only the detected and quantified results. Censored results for bacteria parameters (i.e. non-detect or "present > quantification limit") were handled by substitution: using 0.5 * the lower quantification limit for non-detects and 1.1* the upper quantification limit for results over the test range.

Nutrients

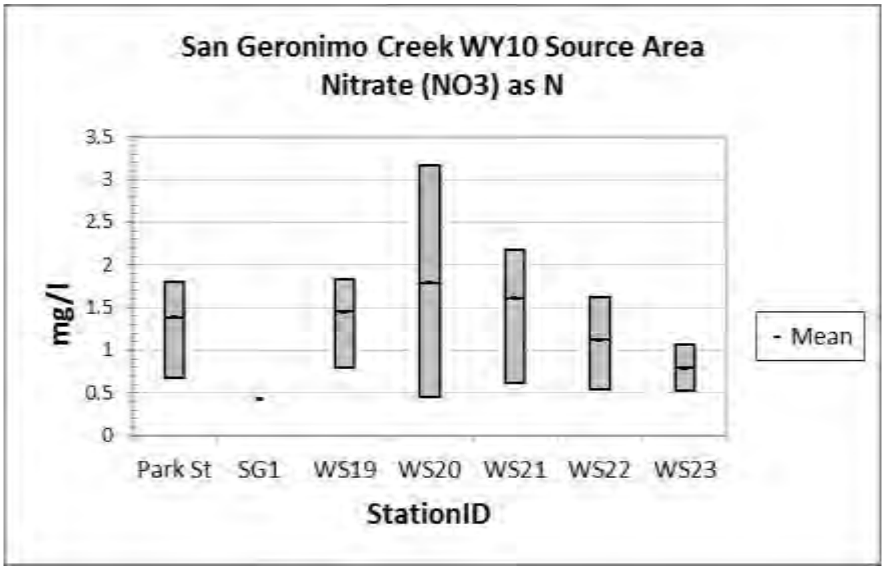
Ammonia

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
Park St	10/13/2009-1/19/2010	1	0.1809	0.1809	0.1809
WS19	10/13/2009-1/19/2010	1	0.1727	0.1727	0.1727
WS20	10/13/2009-1/19/2010	1	0.3125	0.3125	0.3125
WS21	10/13/2009-1/19/2010	1	0.1727	0.1727	0.1727
WS22	10/13/2009-1/19/2010	1	0.1069	0.1069	0.1069



Nitrate

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
Park St	10/13/2009-1/19/2010	3	0.6777	1.807	1.386
SG1	1/19/2010-1/19/2010	1	0.4292	0.4292	0.4292
WS19	10/13/2009-1/19/2010	3	0.7906	1.83	1.453
WS20	10/13/2009-1/19/2010	3	0.4518	3.163	1.792
WS21	10/13/2009-1/19/2010	3	0.6099	2.169	1.612
WS22	10/13/2009-1/19/2010	3	0.5422	1.627	1.122
WS23	12/12/2009-1/19/2010	2	0.5196	1.062	0.7908



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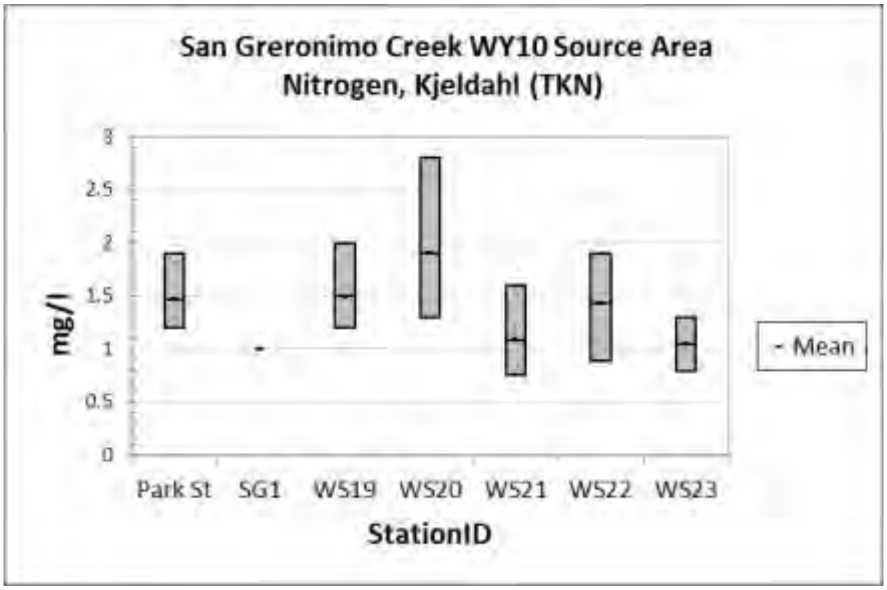
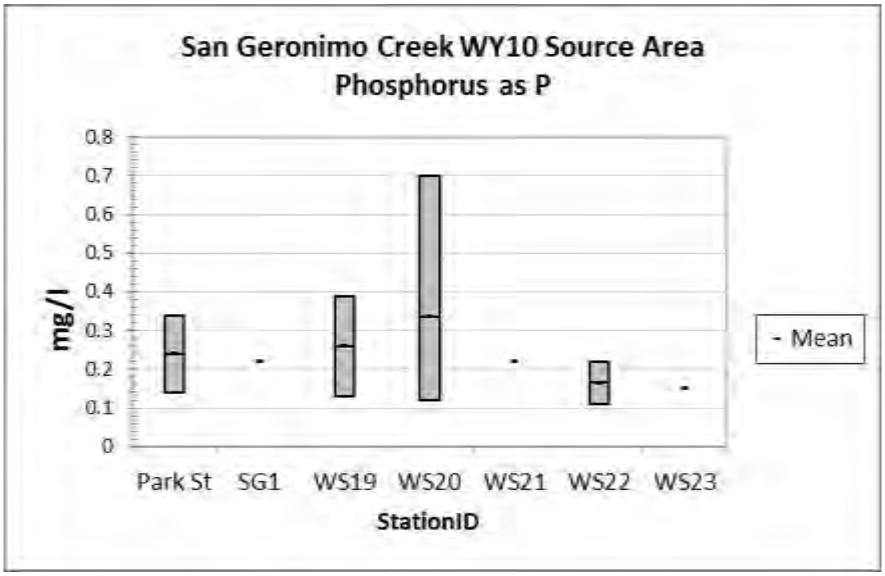
StationID	TimePeriod	# samples	Minimum	Maximum	Mean
Park St	10/13/2009-1/19/2010	3	1.2	1.9	1.467
SG1	1/19/2010-1/19/2010	1	1	1	1
WS19	10/13/2009-1/19/2010	3	1.2	2	1.5
WS20	10/13/2009-1/19/2010	3	1.3	2.8	1.9
WS21	10/13/2009-1/19/2010	3	0.75	1.6	1.083
WS22	10/13/2009-1/19/2010	3	0.89	1.9	1.43
WS23	12/12/2009-1/19/2010	2	0.79	1.3	1.045



Total Phosphorus

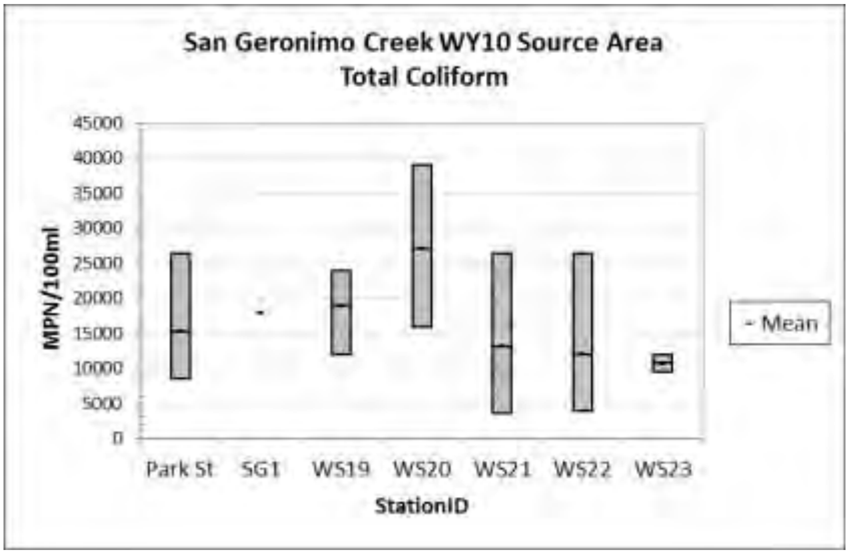
StationID	TimePeriod	# samples	Minimum	Maximum	Mean
Park St	10/13/2009-1/19/2010	2	0.14	0.34	0.24
SG1	1/19/2010-1/19/2010	1	0.22	0.22	0.22
WS19	10/13/2009-1/19/2010	2	0.13	0.39	0.26
WS20	10/13/2009-1/19/2010	3	0.12	0.7	0.3367
WS21	10/13/2009-1/19/2010	1	0.22	0.22	0.22
WS22	10/13/2009-1/19/2010	2	0.11	0.22	0.165
WS23	12/12/2009-1/19/2010	1	0.15	0.15	0.15



Bacteria

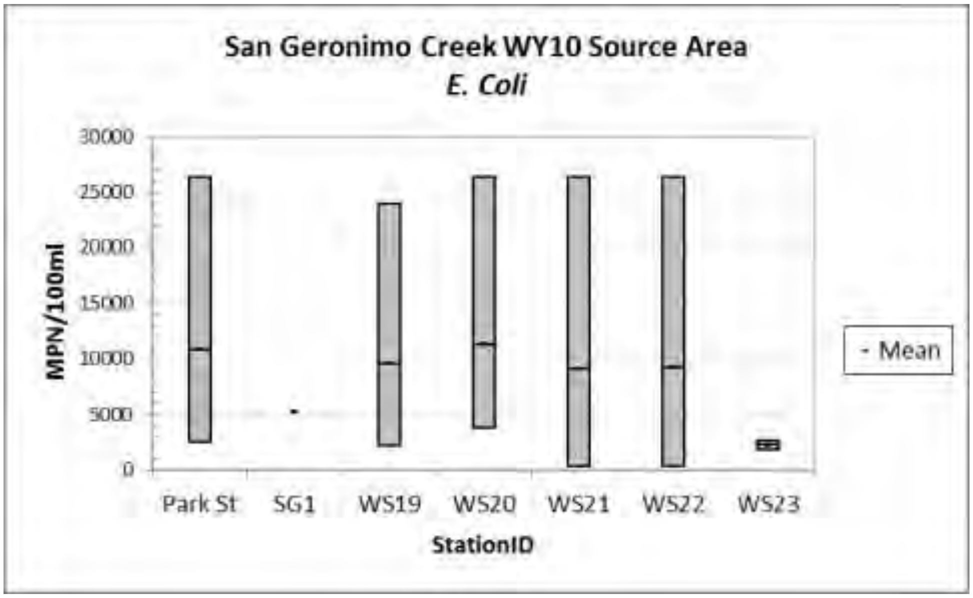
Total Coliform

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
Park St	10/13/2009-1/19/2010	3	8600	26400	15333
SG1	1/19/2010-1/19/2010	1	18000	18000	18000
WS19	10/13/2009-1/19/2010	3	12000	24000	19000
WS20	10/13/2009-1/19/2010	3	16000	39000	27133
WS21	10/13/2009-1/19/2010	3	3600	26400	13200
WS22	10/13/2009-1/19/2010	3	4000	26400	12033
WS23	12/12/2009-1/19/2010	2	9600	12000	10800



E. coli

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
Park St	10/13/2009-1/19/2010	3	2500	26400	10867
SG1	1/19/2010-1/19/2010	1	5200	5200	5200
WS19	10/13/2009-1/19/2010	3	2200	24000	9600
WS20	10/13/2009-1/19/2010	3	3800	26400	11333
WS21	10/13/2009-1/19/2010	3	310	26400	9113
WS22	10/13/2009-1/19/2010	3	310	26400	9270
WS23	12/12/2009-1/19/2010	2	1900	2600	2250



Metals

Cadmium(Cd) – No detections in samples from 12/12/09 (<0.005 mg/L)
Chromium(Cr)- No detections in samples from 12/12/09 (<0.010 mg/L)
Copper (Cu) – No detections in samples from 12/12/09 (<0.050 mg/L)
Silver (Ag) – No detections in samples from 12/12/09 (<0.010 mg/L)
Zinc (Zn) – No detections in samples from 12/12/09 (<0.050 mg/L)
Lead (Pb) - No detections in samples from 12/12/09 (<5.0 µg/L)

MBAS (Methylene Blue Active Substances)

No detections in samples from 10/13/09, not analyzed for subsequent storms

Discussion

The results of Source Area Program sampling in the San Geronimo Creek watershed demonstrate that there are significant concentrations of nutrients and bacteria present across the watershed under storm conditions. The division of the watershed into six or seven hydrologic units by the selected sampling locations provided some additional evidence that even the upper and mid reaches of the watershed (including Woodacre Creek and San Geronimo Creek at Roy's Pools) had very elevated levels of nutrients and bacteria. What is not shown clearly on the graphs is that the first storm sampled on 10/13/2009 was a major early-season event in which the two most downstream sites (SG1 and WS23) were not sampled and which resulted in the most elevated concentrations of bacteria detected during this sampling. Both mainstem and tributary sites demonstrated elevated pollutant concentrations. This suggests multiple sources of pollutant loading at many levels of the watershed. Notable is the elevation of nutrient parameters at WS20 (San Geronimo Creek at Roy's Pools) relative to sites both upstream and downstream. This suggests the possibility of a nutrient source between Woodacre creek and WS20. This section of creek runs through rural residential areas and along a golf course immediately upstream of Roy's Pools.

Past storm sampling at storm drain network sites in Woodacre showed evidence of metals and MBAS. These parameters were not found in the mainstem creek sites in our sampling, likely due to significant dilution from precipitation runoff during the significant rain events sampled.

It should be noted that the pollutant concentration data from this sampling shows the lowest concentrations at the two downstream sites, suggesting improving water quality moving downstream. However, as noted in the opening paragraph of this discussion, these two sites were not sampled during the largest storm event on 10/13/2009 due to safety concerns, and results from that event in particular had some of the highest pollutant concentrations. Also, there are significant inputs of flow volume (including WS21 and WS22) between the mainstem sites WS20, SG1 and WS23, which would result in higher loading rates even with lower pollutant concentrations.

This subwatershed has been a focus of the long-term Trends Program water quality monitoring of one site (SG1) by the TBWC since 2007, and at multiple sites by the RWQCB as part of the Tomales Bay pathogen TMDL. Extensive water quality data from SG1 is available in the main body of this technical report, and in the Trends Sites Storm Profiles watershed report below. Based on the results of all of this monitoring, additional work with the public and private landowners in the watershed would be useful to identify or control potential sources and should be considered a priority focus area for improvement of water quality conditions.

Third Valley Creek Source Area Program Watershed Report

Summary

Third Valley Creek was identified by the WQ TAC in part because of a history of bacteria standards exceedences at Chicken Ranch Beach where Third Valley Creek meets Tomales Bay, and in part because a feasibility study for the restoration of Third Valley Creek and Chicken Ranch Beach was underway. The WQ TAC determined that additional water quality monitoring data would be informative both to the planning process for the potential restoration and to management of an ongoing bacterial contamination issue on Chicken Ranch Beach.

Sampling took place during the 2009-10 winter season between November and April. Five storms were targeted during WY10 including a storm with 0.7" of rain on 11/20/2009; a storm of 0.75" of rain on 12/12/2009, a storm of 1.7"of rain on 1/18/2010, a storm of 1.0"of rain on 3/12/2010 and a storm of 0.9"of rain on 4/5/2010.

Sampling focused on two main areas: the first was the downstream segment of the Third Valley Creek watershed where the creek approaches the flat valley bottom and is conveyed through long culverts and heavily altered channel to the beach. The second was the drainage to the north of the creek and beach from Seahaven (a residential area at the north end of the lower watershed). Some of this drainage is conveyed to Third Valley Creek upstream of the culverts under Sir Francis Drake Blvd., and some is collected in a ditch at the toe of the hill and conveyed via a dogleg ditch onto the beach through public and private lands.

Sites along Third Valley Creek itself, from upstream to downstream were: CR6, a mainstem site upstream of development; CR5b and CR5a, the upstream and downstream ends of a tributary from SFD Blvd.; CR5, a mainstem site adjacent to the Inverness Valley Inn; CR4, a mainstem site just upstream of the double-barrel culverts under SFD Blvd.; CDM1, the discharge culvert under SFD Blvd. from Camino del Mar which enters the creek at CR4; CR2, a mainstem site upstream of CR2C; CR2C, a culvert from the west side of SFD Blvd.; and CR1, a mainstem site at the pedestrian bridge to Chicken Ranch Beach. Sites in the secondary drainage were: CRB2, a site at the upstream end of the artificial channel or ditch carrying water from the two of the hill to the beach; CRB, the pool or channel of water formed on the north end of the beach – also known as "channel B"; and TP1, water in the small pond adjacent to the beach – also known as "Turtle Pond". Not all sites were sampled during each event, depending on flow conditions and results from previous sampling. Measurements of field parameters (water temperature, Specific Conductance, salinity, dissolved oxygen and pH) were made after collecting lab samples from the site. Lab samples were analyzed for bacteria (Total coliform and *E. coli*), nutrients (Ammonia, nitrate, total Kjeldahl nitrogen, total phosphorus), and sediment (turbidity) according to the following summary table.

Sampling Events Summary

Sub-Watershed	Sampling Date	# of sampled Sites	Parameters
Third Valley Creek	11/20/2009	3	Bacteria, Nutrients, Sediment and Field (DO, pH, Temp., SC)
	12/12/2009	5	
	1/18/2010	8	
	3/12/2010	6	
	4/5/2010	9	

Third Valley Creek Source Area Sampling Site Map

Monitoring Results

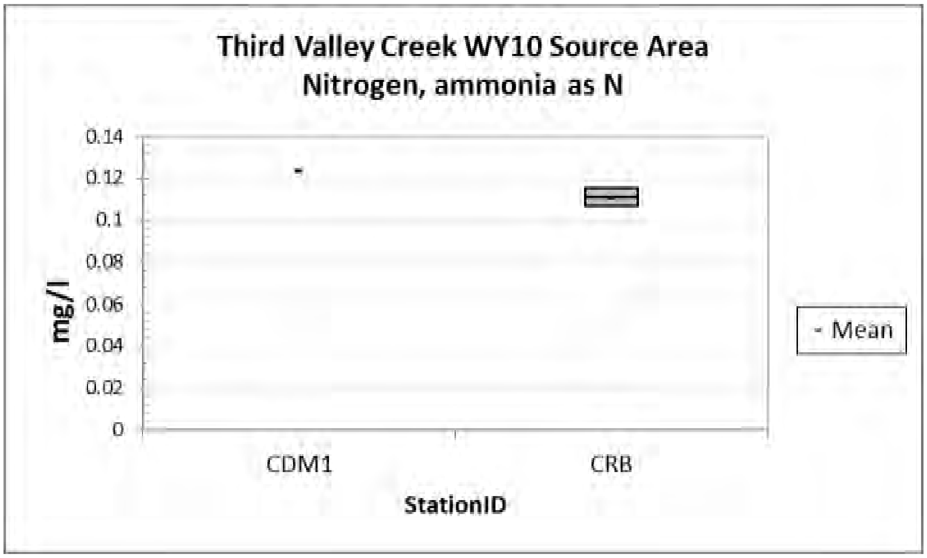
The section below details the range of results from the five sampling events at Source Area Program sites in Third Valley Creek. The tables below show the number of samples from each site that had quantifiable results for the parameter of interest. The figures below provide box graphs of results for each parameter with maximum, minimum and mean indicated. If only one result was quantified for a site, the point is indicated on the graph by the mean symbol.

Censored results (i.e. non-detects) were excluded from the tables and graphs for nutrients and sediment, so the "# of samples" column in each table contains only the detected and quantified results. Censored results for bacteria parameters (i.e. non-detect or "present > quantification limit") were handled by substitution: using 0.5 * the lower quantification limit for non-detects and 1.1* the upper quantification limit for results over the test range.

Nutrients

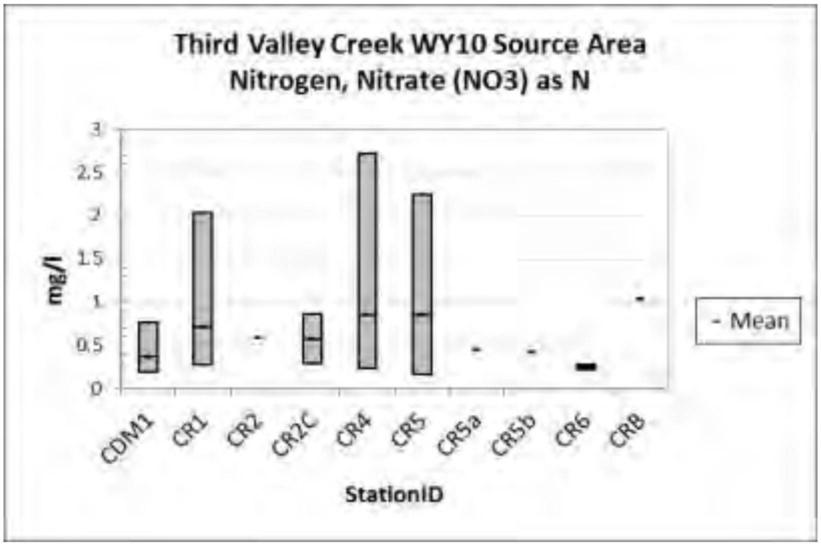
Ammonia

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
CDM1	11/20/2009-4/5/2010	1	0.1234	0.1234	0.1234
CRB	1/18/2010-4/5/2010	2	0.1069	0.1151	0.111



Nitrate

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
CDM1	11/20/2009-4/5/2010	5	0.1988	0.768	0.3682
CR1	11/20/2009-4/5/2010	5	0.2711	2.033	0.7094
CR2	12/12/2009-12/12/2009	1	0.587	0.587	0.587
CR2C	1/18/2010-4/5/2010	2	0.2937	0.858	0.5758
CR4	11/20/2009-4/5/2010	5	0.23	2.711	0.8502
CR5	12/12/2009-4/5/2010	4	0.1694	2.236	0.8498
CR5a	4/5/2010-4/5/2010	1	0.4518	0.4518	0.4518
CR5b	4/5/2010-4/5/2010	1	0.4292	0.4292	0.4292
CR6	3/12/2010-4/5/2010	2	0.2169	0.2711	0.244
CRB	1/18/2010-1/18/2010	1	1.039	1.039	1.039



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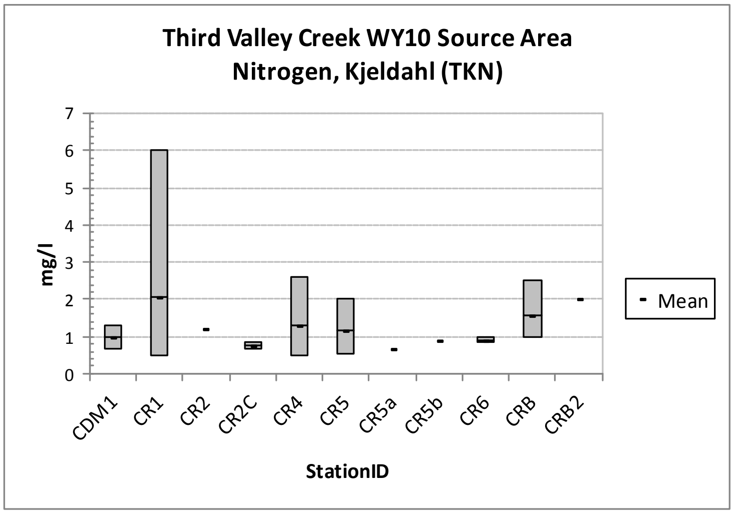
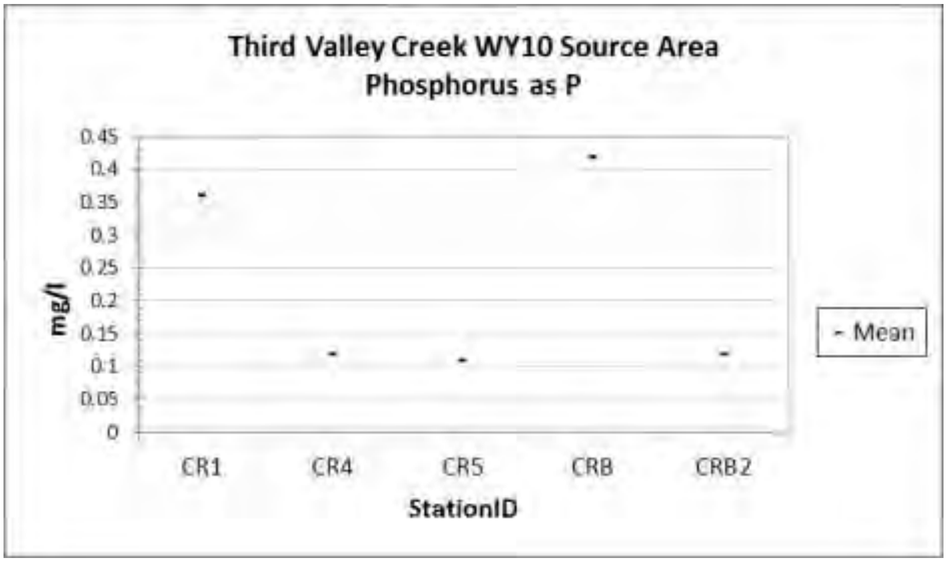
StationID	TimePeriod	# samples	Minimum	Maximum	Mean
CDM1	11/20/2009-4/5/2010	5	0.65	1.3	0.996
CR1	11/20/2009-4/5/2010	5	0.51	6	2.046
CR2	12/12/2009-12/12/2009	1	1.2	1.2	1.2
CR2C	1/18/2010-4/5/2010	2	0.65	0.86	0.755
CR4	11/20/2009-4/5/2010	5	0.47	2.6	1.32
CR5	12/12/2009-4/5/2010	4	0.55	2	1.18
CR5a	4/5/2010-4/5/2010	1	0.68	0.68	0.68
CR5b	4/5/2010-4/5/2010	1	0.9	0.9	0.9
CR6	3/12/2010-4/5/2010	2	0.83	1	0.915
CRB	1/18/2010-4/5/2010	3	1	2.5	1.567
CRB2	1/18/2010-1/18/2010	1	2	2	2



Total Phosphorus

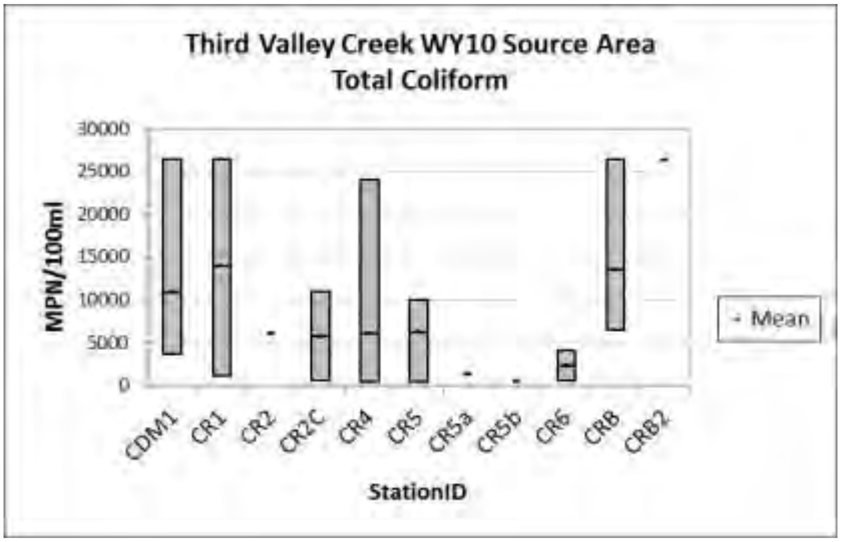
StationID	TimePeriod	# samples	Minimum	Maximum	Mean
CR1	11/20/2009-4/5/2010	1	0.36	0.36	0.36
CR4	11/20/2009-4/5/2010	1	0.12	0.12	0.12
CR5	12/12/2009-4/5/2010	1	0.11	0.11	0.11
CRB	1/18/2010-4/5/2010	1	0.42	0.42	0.42
CRB2	1/18/2010-1/18/2010	1	0.12	0.12	0.12



Bacteria

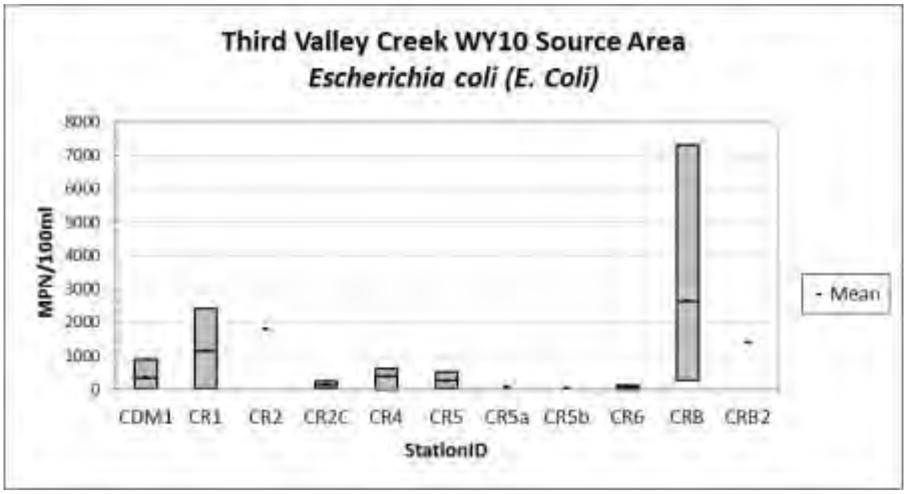
Total Coliform

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
CDM1	11/20/2009-4/5/2010	5	3700	26400	10860
CR1	11/20/2009-4/5/2010	5	1200	26400	14000
CR2	12/12/2009-12/12/2009	1	6100	6100	6100
CR2C	1/18/2010-4/5/2010	2	570	11000	5785
CR4	11/20/2009-4/5/2010	5	450	24000	6130
CR5	12/12/2009-4/5/2010	4	490	10000	6222
CR5a	4/5/2010-4/5/2010	1	1400	1400	1400
CR5b	4/5/2010-4/5/2010	1	560	560	560
CR6	3/12/2010-4/5/2010	2	570	4100	2335
CRB	1/18/2010-4/5/2010	3	6500	26400	13533
CRB2	1/18/2010-1/18/2010	1	26400	26400	26400



E. coli

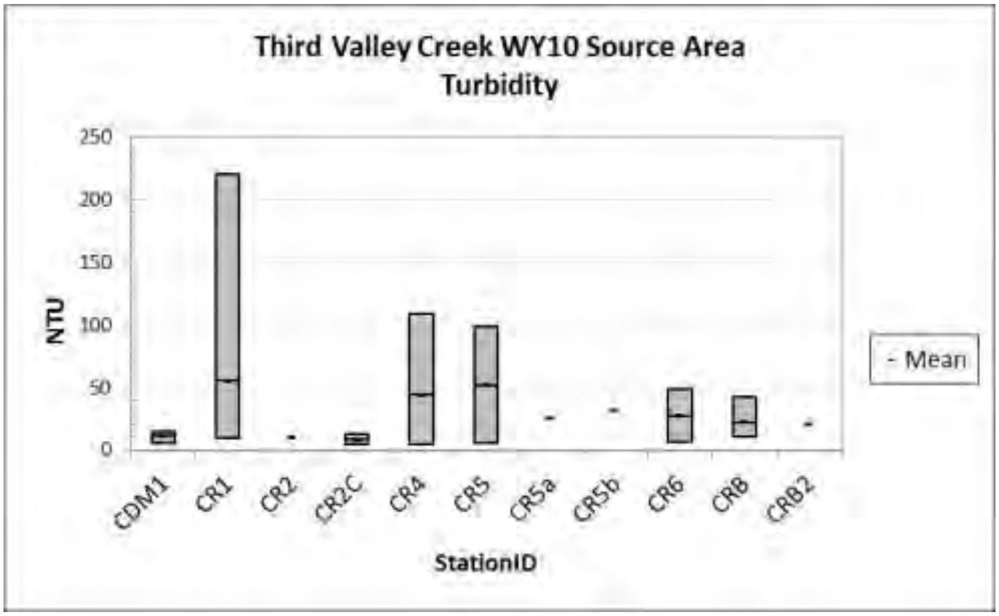
StationID	TimePeriod	# samples	Minimum	Maximum	Mean
CDM1	11/20/2009-4/5/2010	5	20	880	348
CR1	11/20/2009-4/5/2010	5	31	2400	1150
CR2	12/12/2009-12/12/2009	1	1800	1800	1800
CR2C	1/18/2010-4/5/2010	2	20	230	125
CR4	11/20/2009-4/5/2010	5	5	630	395
CR5	12/12/2009-4/5/2010	4	20	530	261.8
CR5a	4/5/2010-4/5/2010	1	85	85	85
CR5b	4/5/2010-4/5/2010	1	41	41	41
CR6	3/12/2010-4/5/2010	2	5	120	62.5
CRB	1/18/2010-4/5/2010	3	280	7300	2633
CRB2	1/18/2010-1/18/2010	1	1400	1400	1400



Sediment

Turbidity

StationID	TimePeriod	# samples	Minimum	Maximum	Mean
CDM1	11/20/2009-4/5/2010	5	5.62	15.2	11.68
CR1	11/20/2009-4/5/2010	5	9.34	220	55.39
CR2	12/12/2009-12/12/2009	1	10.7	10.7	10.7
CR2C	1/18/2010-4/5/2010	2	4.23	12.6	8.415
CR4	11/20/2009-4/5/2010	5	4.53	109	44.33
CR5	12/12/2009-4/5/2010	4	5.76	98.9	51.72
CR5a	4/5/2010-4/5/2010	1	25.3	25.3	25.3
CR5b	4/5/2010-4/5/2010	1	32	32	32
CR6	3/12/2010-4/5/2010	2	6.53	48.2	27.36
CRB	1/18/2010-4/5/2010	3	10.8	42.1	22.03
CRB2	1/18/2010-1/18/2010	1	20.7	20.7	20.7



Discussion

The results of Source Area Program sampling in the Third Valley Creek watershed suggest elevated levels of sediment, nutrients and bacteria, generally increasing from upstream to down with some evidence of source areas or reaches. The levels of nutrients are elevated, but not relative to other similar streams in the watershed under storm conditions. The results suggest nitrogen sources in the middle and lower watershed, but a phosphorus source only in the lower watershed. The turbidity increased at sites downstream in the main channel. Both total coliform and E. coli bacteria levels also increased at sites moving downstream. Limited sample numbers from the CR2 and CR2C limits the value of conclusions for conditions between CR4 and CR1. The results from CDM1, CRB2 and CRB also demonstrate that the runoff from Seahaven down Camino del Mar is carrying significant levels of pollutants. The elevated bacteria levels seen in samples from CDM1 and from the most downstream from this drainage (CRB) suggest that this part of the watershed is a significant contributing factor to the persistent exceedence of water contact standards seen in Channel B on the public beach. The water from CRB flows across the public beach and into the mainstem of Third Valley Creek just downstream from CR1.

The lower end of this watershed is the subject of a restoration feasibility study for Third Valley Creek and Chicken Ranch Beach produced by the TBWC (Kamman et al 2013), and considerable water quality sampling was conducted as part of the assessment to determine the source, characteristics and pattern of bacterial contamination. The sum of the evidence suggests that the persistent source of bacterial contamination is Channel B, and that the fact that this drainage empties onto, then flows across the length of the public beach under wet conditions increases the likelihood of direct contact with the water.

Additional work with the public and private landowners in the watershed would be useful to implement measures to control potential sources of contamination and should be considered a priority focus area for improvement of water quality conditions.

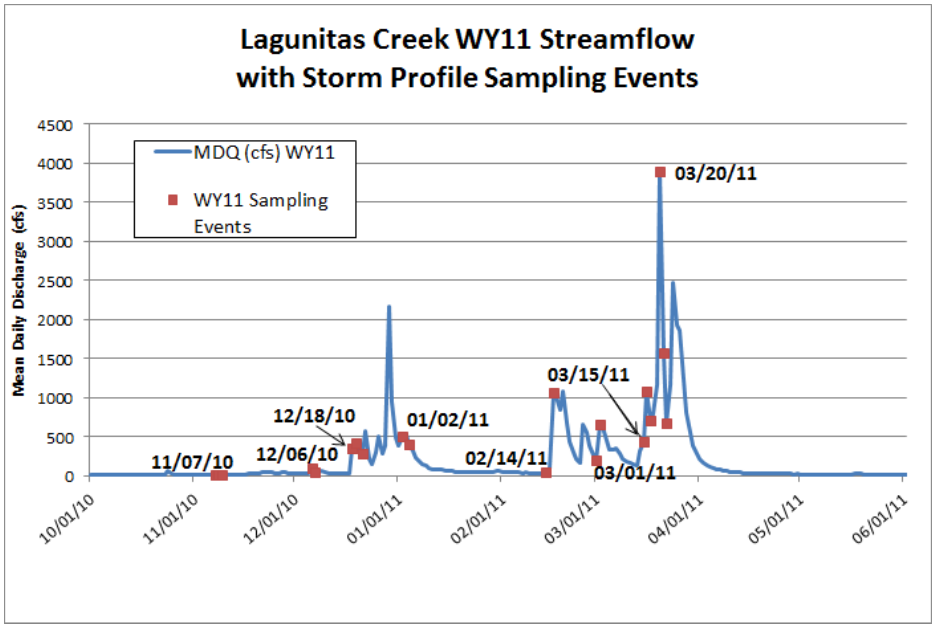
Trend Site Source Area Program Storm Profiles
Watershed Report

Summary

In the spring of 2010 the WQ TAC determined that remaining Source Area Program funding would be used to target selected Trends sites in major watersheds with intensive storm profile sampling (i.e. rising, falling limb, 1, 2 and/or 3, 4, 5-days after a significant rain event) around 3-5 storm events each winter for bacteria, nutrient and sediment parameters. The goal would be to gain an understanding not only of the magnitude and duration of pollutant loading in major contributing sub-watersheds, but also whether there are thresholds of precipitation that correspond to loading events, or distinct differences between watershed responses.

This methodology was implemented during the 2011 water-year, and took place at TBWC Trends Program sites in the Millerton Gulch and San Geronimo, Olema and First Valley Creeks. The close spacing of storms during WY11 frustrated attempts to gather the latter (day3-5) samples, however differences between monitored watersheds were observed. Additionally, the three Trends Program sites in the Walker Creek watershed (KYS1, WKR2 and WKR1) were targeted for storm profiles during a single storm in WY11 and one storm in WY12.The four Trends Program sites chosen for the initial WY11 sampling were selected to represent a range of small to medium-sized subwatersheds with differing levels of pollutants and varied land uses.

Sampling took place during the 2010-11 winter season between November and March. Profiles of pollutant concentrations (*E. coli*, nitrate, TKN and turbidity) from eight sampling series during WY11 were compiled. The periods profiled include: November 7-9, 2010; December 6-7, 2010; December 18-21, 2010; January 2-4, 2011; February 14-16, 2011; March 1-2, 2011; March 15-17, 2011; March 20-22, 2011. See the graph below for the discharge hydrograph from the downstream Lagunitas Creek streamgage including the WY11 Source Area sampling events.

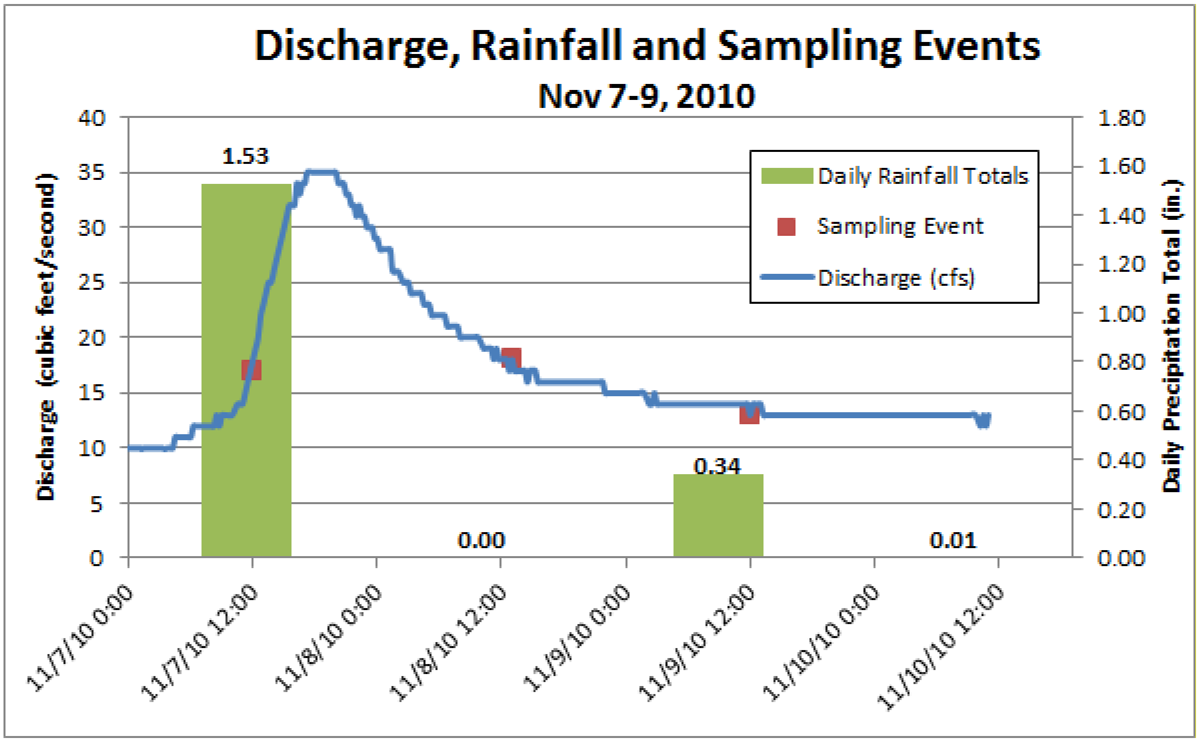


The results from the Source Area Program storm profiles of San Geronimo Creek, Olema Creek, First Valley Creek and Millerton Gulch are presented immediately below. The results from the storm profiles of Walker Creek sites follow in the WY12 section (on page F52).

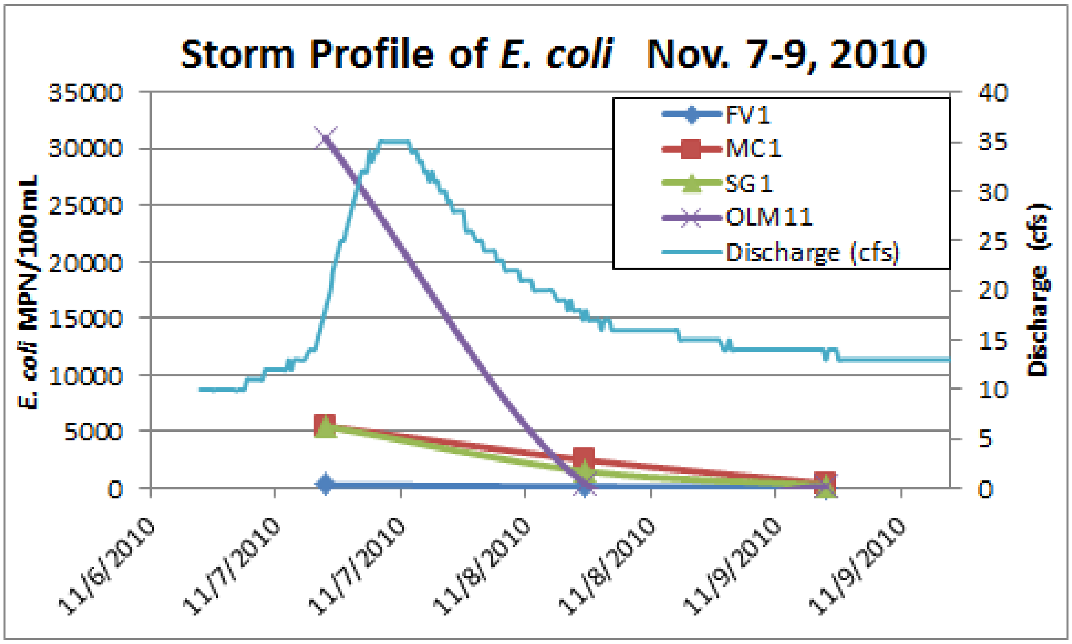
November 7-9, 2010 Storm Profile

The first storm that was targeted for profile sampling was an early season storm of over 1.5-inches on November 7th, 2010. The cumulative precipitation for WY11 before the Nov. 7th storm was less than 6 inches, and more than a week had passed since the last significant rainfall. Under these conditions, the soils in the watershed were not yet saturated, so the hydrologic response seen in the gaged creeks was muted relative to similar sized storms later in the season. Also, under these conditions, we would expect that some upstream sources may still be disconnected from the mainstems of larger subwatersheds. It is possible, however, that some small-to-medium-sized subwatersheds experienced first flush events during this storm.

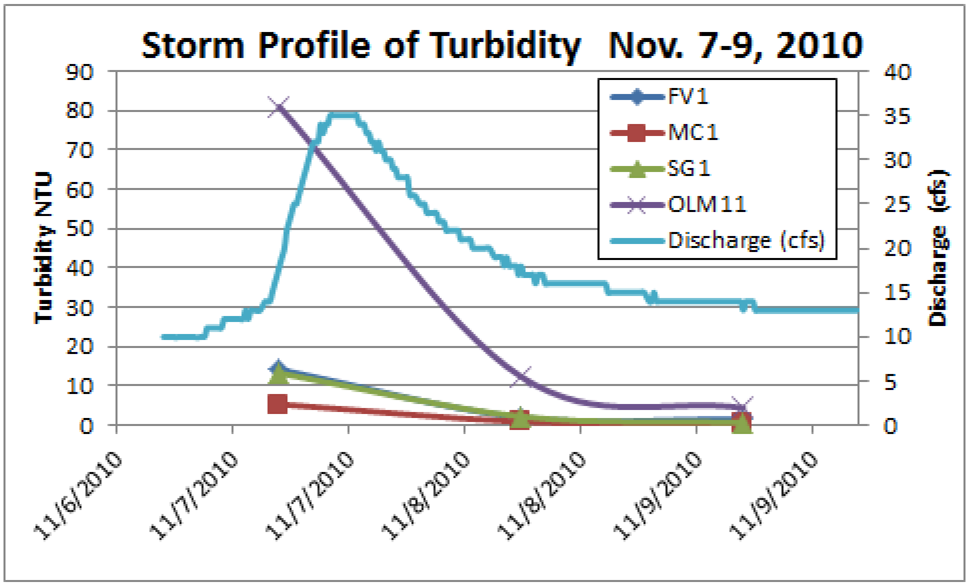
Below is a graph of hydrologic conditions during the storm period including the stream discharge from the streamgage on lower Lagunitas Creek near Point Reyes Station (USGS gage 11460600), the daily rainfall totals (from the RAWS weather station OVYC1 in the Olema Valley) and the creek site water quality sampling events.



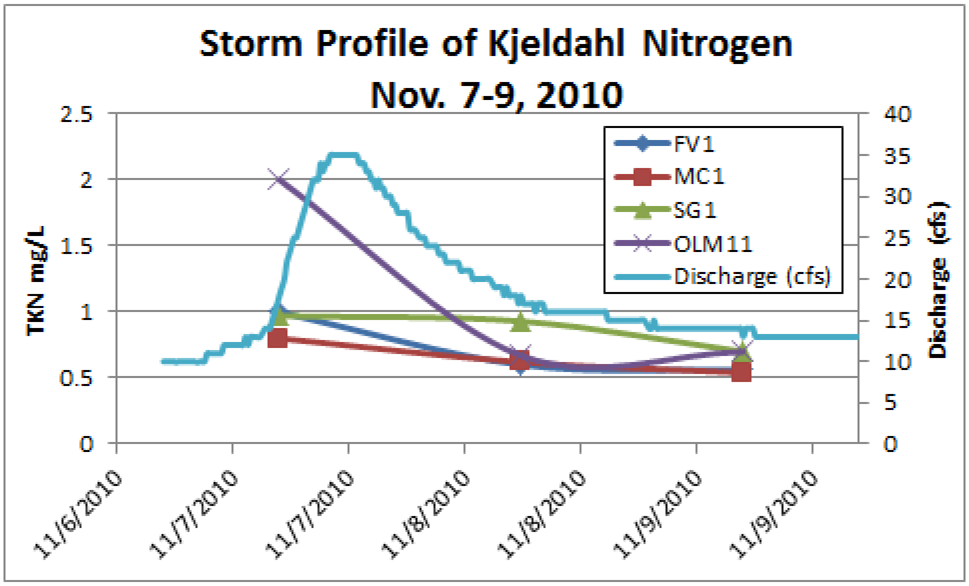
A second, smaller precipitation event on November 9th interrupted the planned 4th and 5th day post-storm sampling, but results from the samples on days 1, 2 and 3 are below. Time series graphs including the hydrograph from Lagunitas Creek and each site's pollutant concentration is presented for each parameter for the sampled period are below.



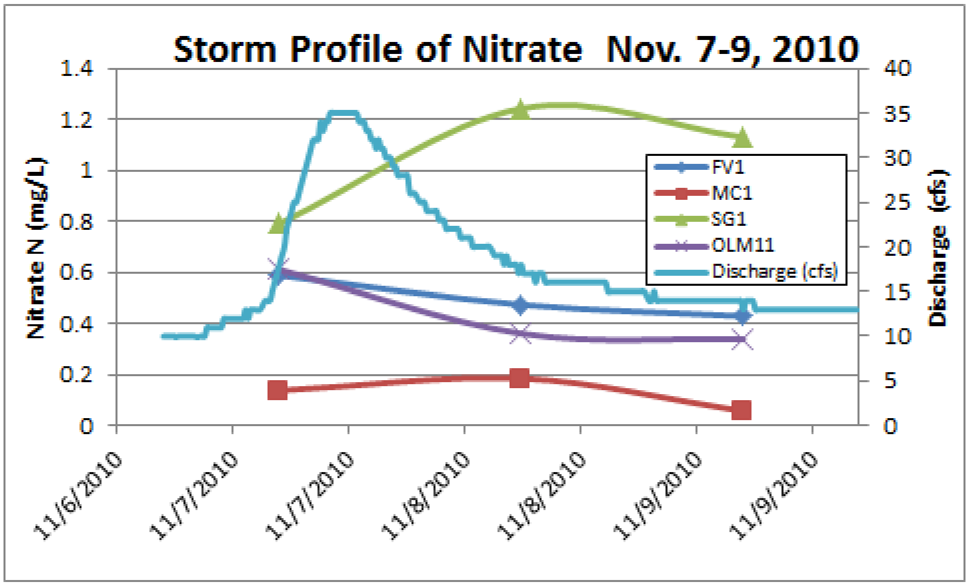
The results of bacteria testing for *E. coli* shows levels for all sampled creeks were highest during the first day of sampling, during the rain event, which is a typical pattern for pollution runoff. Although the levels of bacteria in Olema Creek were remarkably high on day one, suggesting that some upstream sources were flushing out during this early season storm.



The timeseries plot of turbidity demonstrates relatively low levels of turbidity at all four sites, even at the peak measured on day one. The levels seen on all three days were similar across First Valley Creek, Millerton Gulch and San Geronimo Creek. Olema Creek showed a much higher peak near 80 NTU on day one, but quickly fell back to typical early season levels.



The timeseries graph of total Kjeldahl nitrogen (TKN) shows a similar pattern as both the *E. coli* and turbidity results, with all sites having their highest peak on day one and a general declining trend on days two and three. This association between turbidity, TKN and bacteria would be expected given that much of the organic nitrogen in the system is associated with soil and vegetative material, and bacteria are often carried downstream on soil particles.



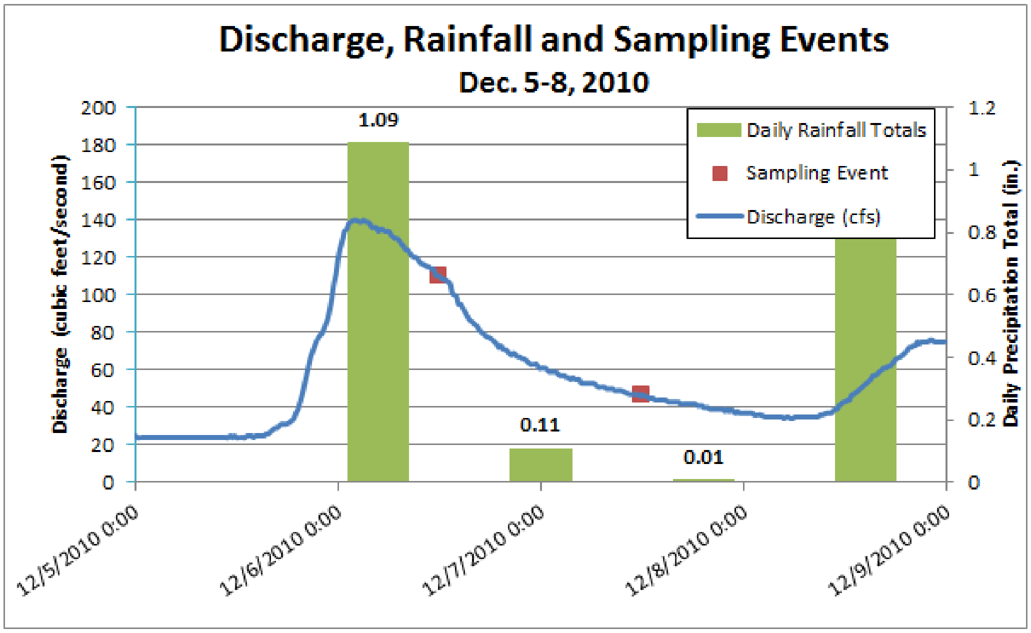
The timeseries graph of nitrate concentrations shows a different pattern with peak levels measured on San Geronimo Creek on all three days (although levels were relatively low). The measurements also demonstrate a delayed response, with the peak nitrate levels being measured on day two. This suggests the early season flushing of upstream nitrate sources in the watershed, with the loads being carried by subsiding flows to the mainstem and downstream. Nitrate is chronically high in this watershed, as can be seen from the results of Trends Program sampling at the San Geronimo Creek site in the main body of this report, and in the San Geronimo Creek Watershed Report in section III.c. of this appendix.

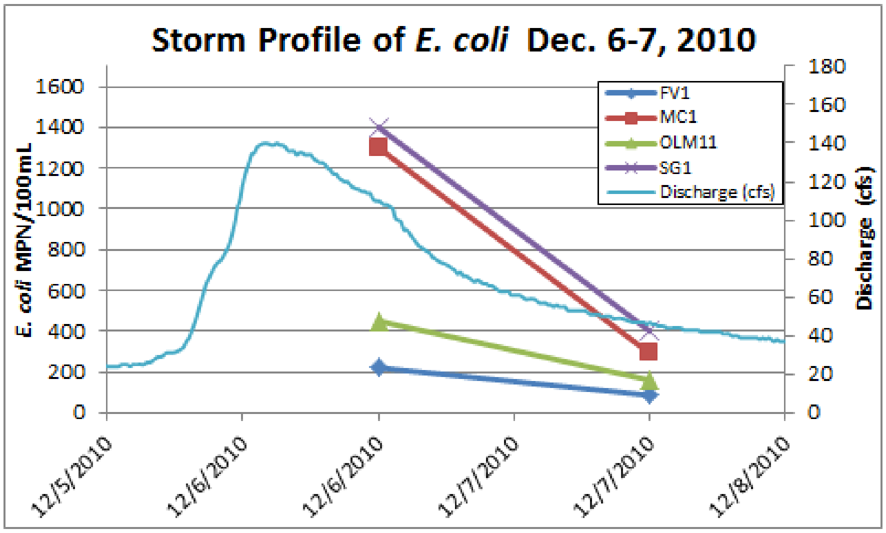
December 5-7, 2010 Storm Profile

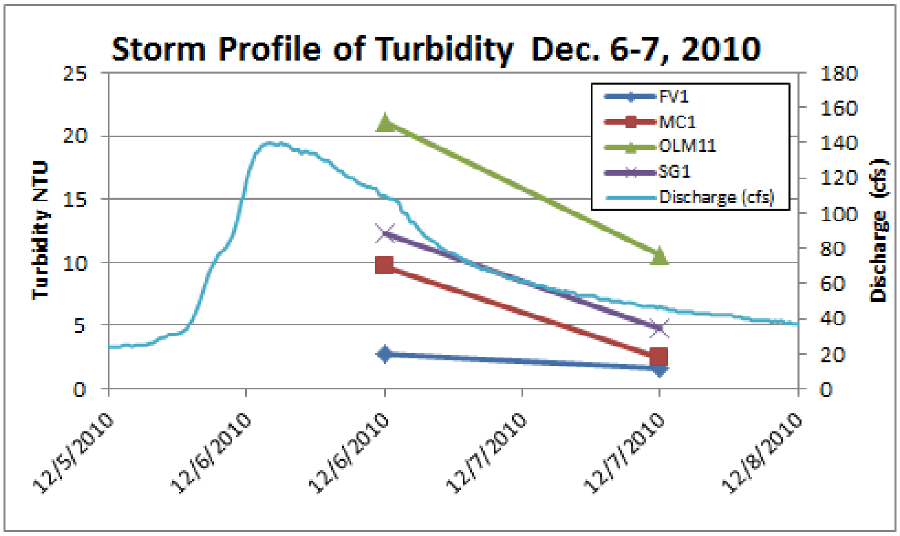
The second storm that was targeted for profile sampling was another early season storm of over 1 inch on December 5-6th, 2010. The cumulative precipitation for WY11 before this storm was less than 12 inches, and more than a week had passed since the last significant rainfall. Under these conditions, the soils in the watershed were still not yet saturated, so the hydrologic response seen in the gaged creeks was muted relative to similar sized storms later in the season. Rains on December 8th interrupted the later sampling of the storm profile from the December 5th rains.

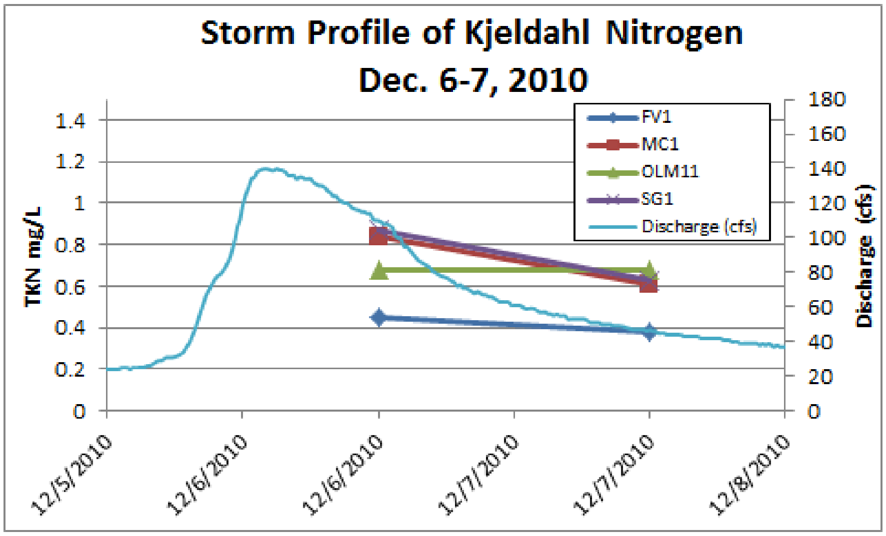
With cumulative annual rainfall to date at nearly 12-inches, much of which occurred in 1-2-inch storms in late October or November, first flush of smaller watersheds or tributaries had likely occurred, although not all upstream sources were yet connected to mainstem creeks.

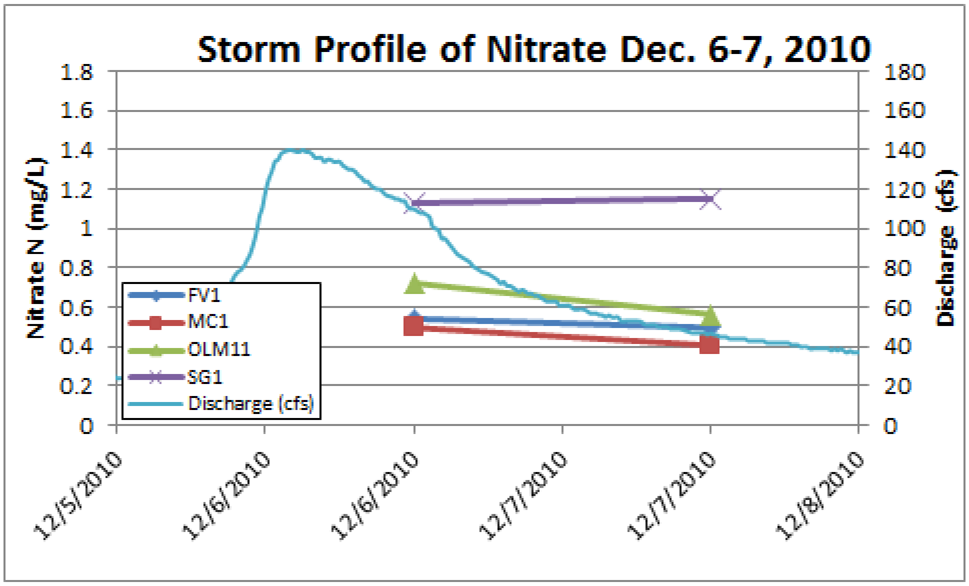
Below is a graph of hydrologic conditions during the storm period including the stream discharge from the streamgage on lower Lagunitas Creek near Point Reyes Station (USGS gage 11460600), the daily rainfall totals (from the RAWS weather station OVYC1 in the Olema Valley) and the creek site water quality sampling events.




Storm Profile of *E. coli* Dec. 6-7, 2010


Storm Profile of Turbidity Dec. 6-7, 2010


Storm Profile of Kjeldahl Nitrogen Dec. 6-7, 2010



Concentrations of bacteria, sediment and TKN all declined between the day one and day two samples with San Geronimo Creek and Millerton Gulch showing the highest levels of bacteria and TKN, with Olema showing higher turbidity levels than the other three sites.

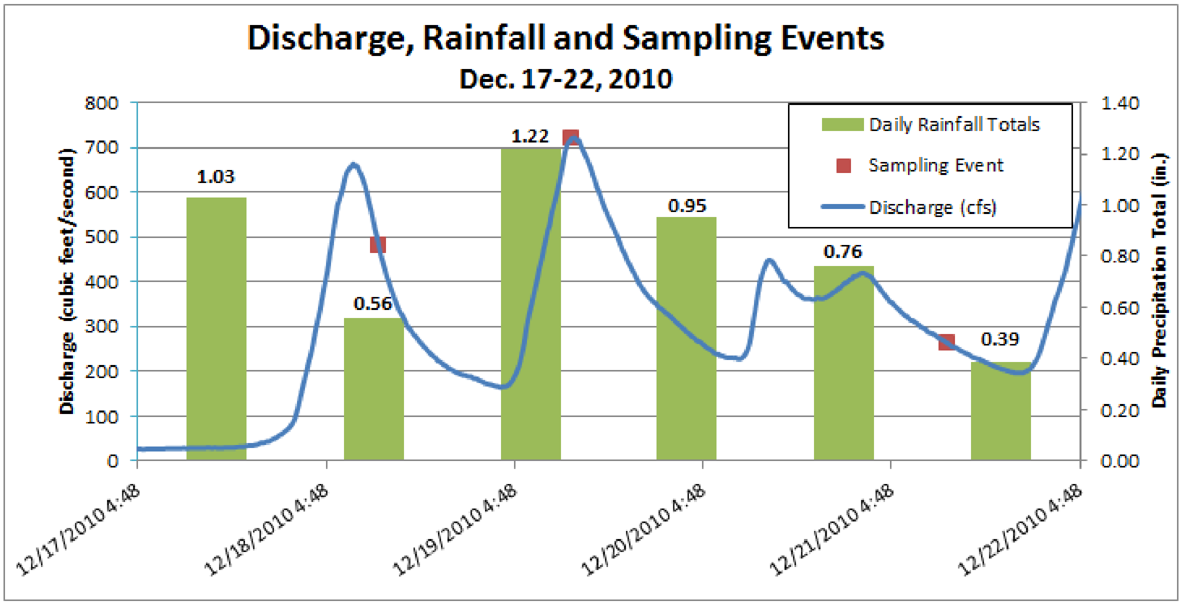
Nitrate results during this storm show a minor decrease between the day one and day two samples for most sites, except for San Geronimo Creek which also showed the highest nitrate results among the sampled streams.

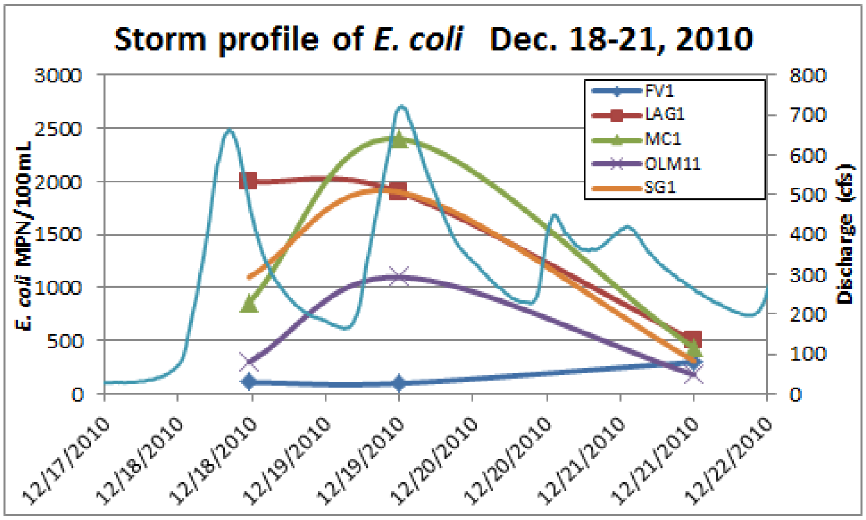
It should be noted that the concentrations of pollutants measured during this storm event were relatively low. This was likely due to the storm's size and it's arrival during the early-season.

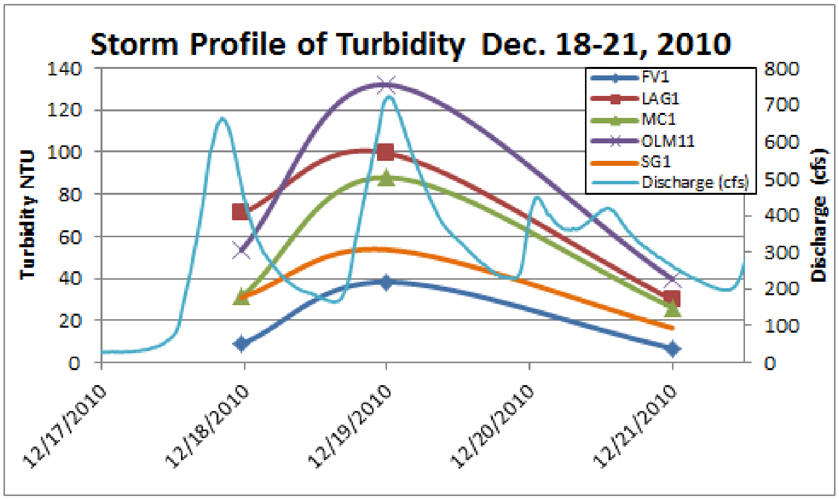
December 18-21, 2010 Storm Profile

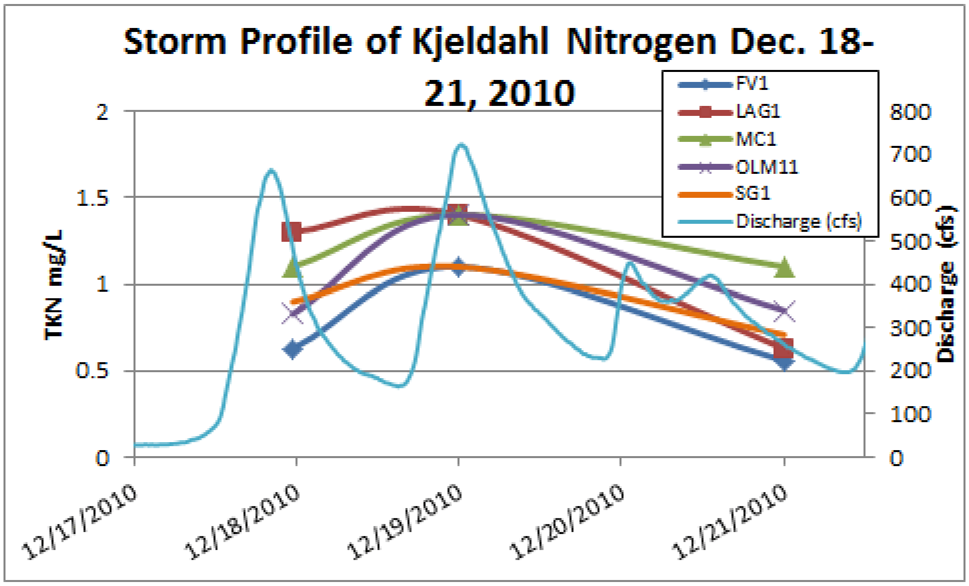
The third storm that was targeted for profile sampling was a storm of 1-1.5 inches on December 17-18th, 2010. Rains continued for the next 5 days, with daily precipitation totals over 0.5-inches each day. Samples were collected on day one (12/18), day two (12/19) and day four (12/21). This storm sampling series does not provide a profile of pollutants through a discrete event, but rather provides a profile of concentrations as they exist under sustained storm conditions which are typical of wet-season periods in these watersheds.

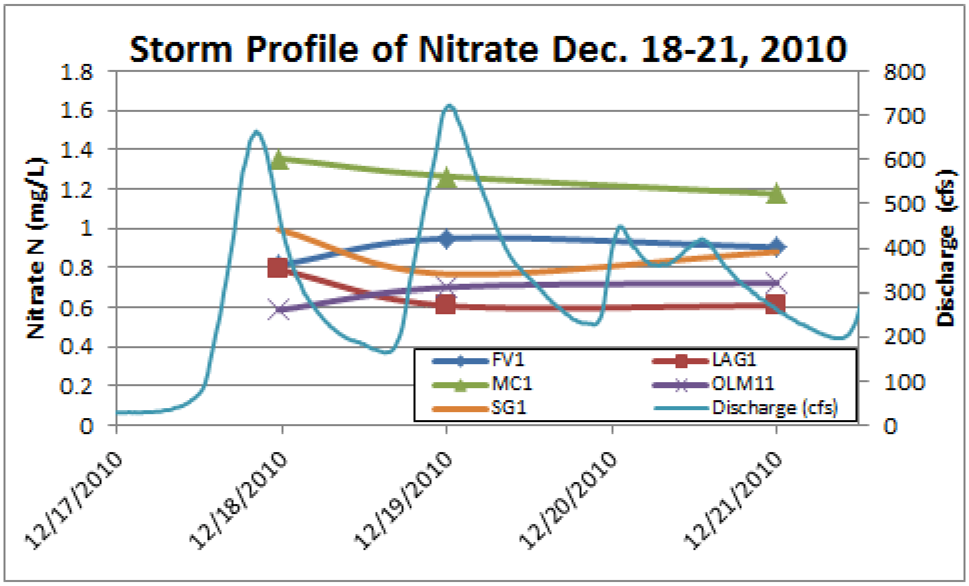
Below is a graph of hydrologic conditions during the storm period including the stream discharge from the streamgage on lower Lagunitas Creek near Point Reyes Station (USGS gage 11460600), the daily rainfall totals (from the RAWS weather station OVYC1 in the Olema Valley) and the creek site water quality sampling events.


Discharge, Rainfall and Sampling Events
Dec. 17-22, 2010
Discharge (cubic feet/second)
Daily Precipitation Total (in.)
800
700
600
500
400
300
200
100
0
1.40
1.20
1.00
0.80
0.60
0.40
0.20
0.00
1.03
0.56
1.22
0.95
0.76
0.39
Daily Rainfall Totals
Sampling Event
Discharge (cfs)
12/17/2010 4:48
12/18/2010 4:48
12/19/2010 4:48
12/20/2010 4:48
12/21/2010 4:48
12/22/2010 4:48


Storm profile of E. coli Dec. 18-21, 2010
E. coli MPN/100mL
Discharge (cfs)
3000
2500
2000
1500
1000
500
0
800
700
600
500
400
300
200
100
0
FV1
LAG1
MC1
OLM11
SG1
12/17/2010
12/18/2010
12/18/2010
12/19/2010
12/19/2010
12/20/2010
12/20/2010
12/21/2010
12/21/2010
12/22/2010


Storm Profile of Turbidity Dec. 18-21, 2010
Turbidity NTU
Discharge (cfs)
140
120
100
80
60
40
20
0
800
700
600
500
400
300
200
100
0
FV1
LAG1
MC1
OLM11
SG1
Discharge (cfs)
12/17/2010
12/18/2010
12/19/2010
12/20/2010
12/21/2010



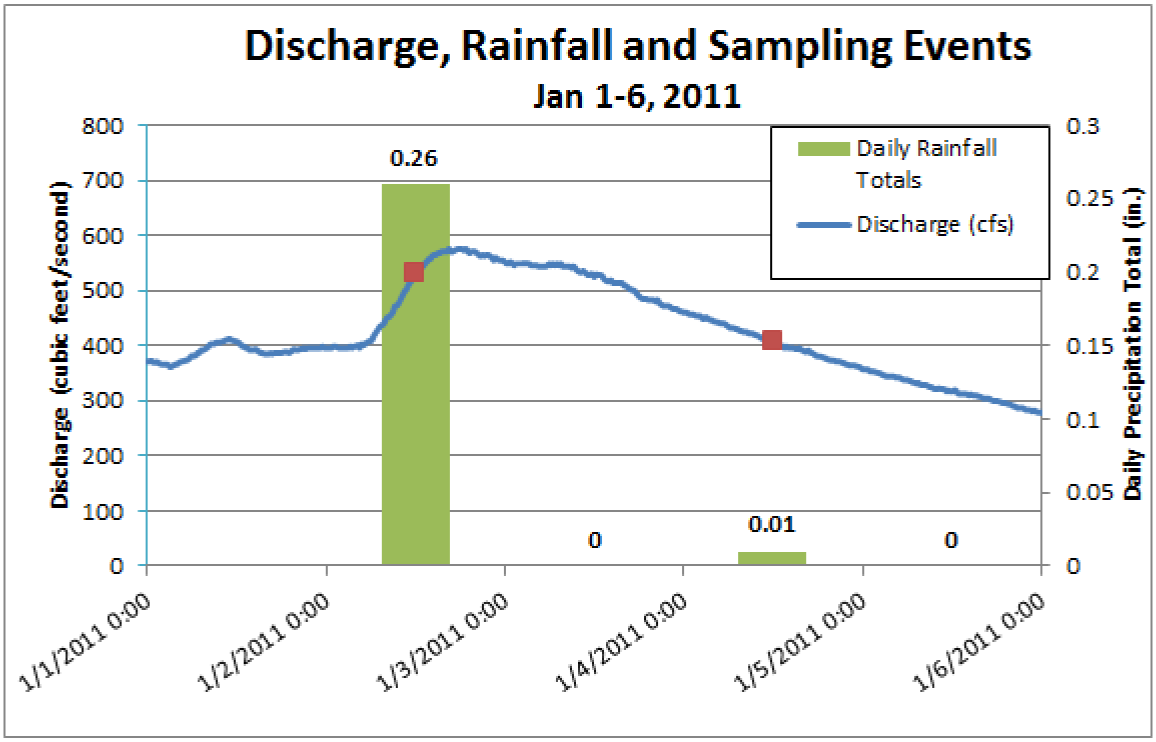


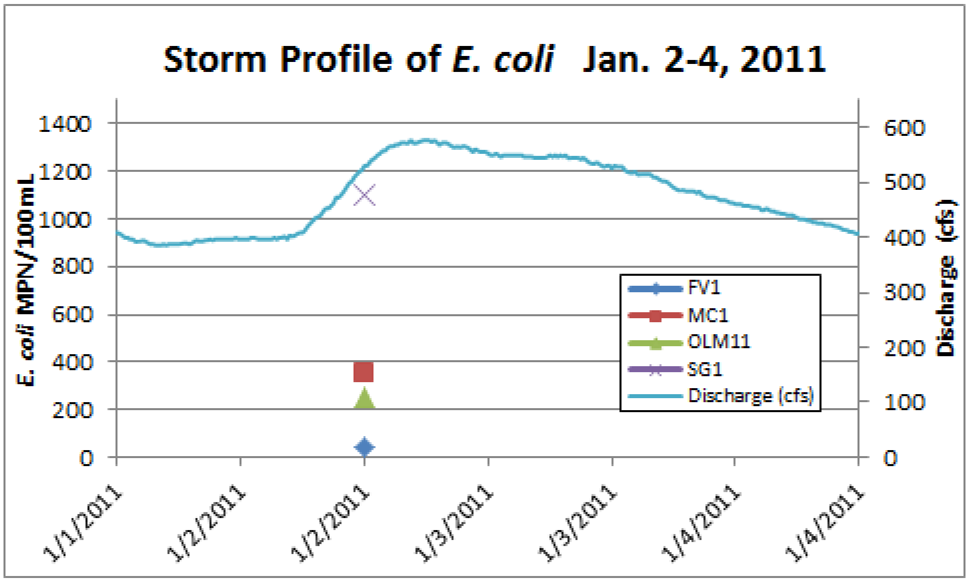
There is a familiar pattern of peak loads measured during peak flows, with concentrations of bacteria, sediment and TKN tapering off over time as the storm flows recede. Again, the highest sediment levels were seen in Olema Creek, but the highest bacteria results came from San Geronimo Creek, Millerton Gulch and lower Lagunitas Creek. The pattern for nitrate shows relatively consistent concentrations measured across the hydrograph, with the highest results coming from Millerton Gulch samples.

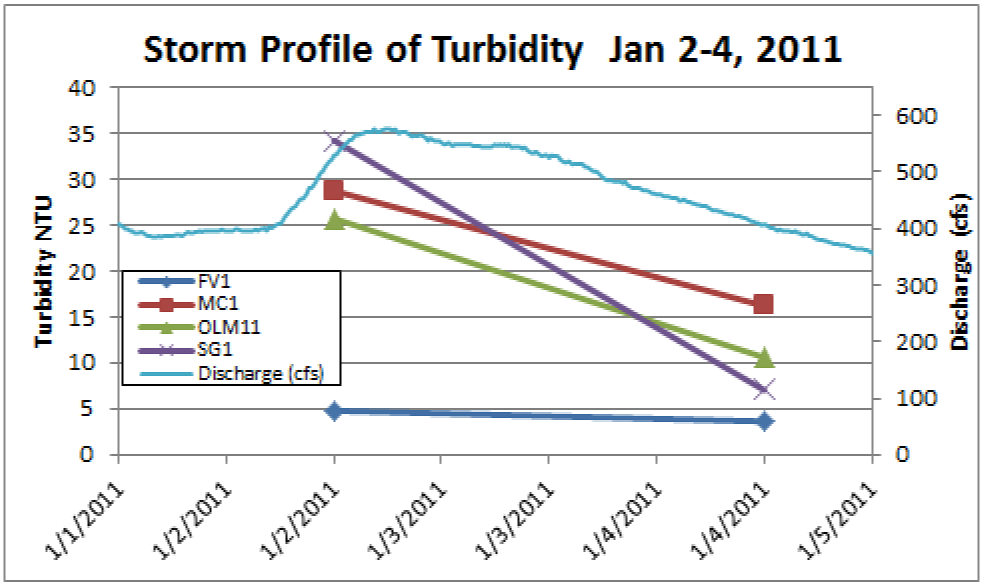
January 3, 2011 Storm Profile

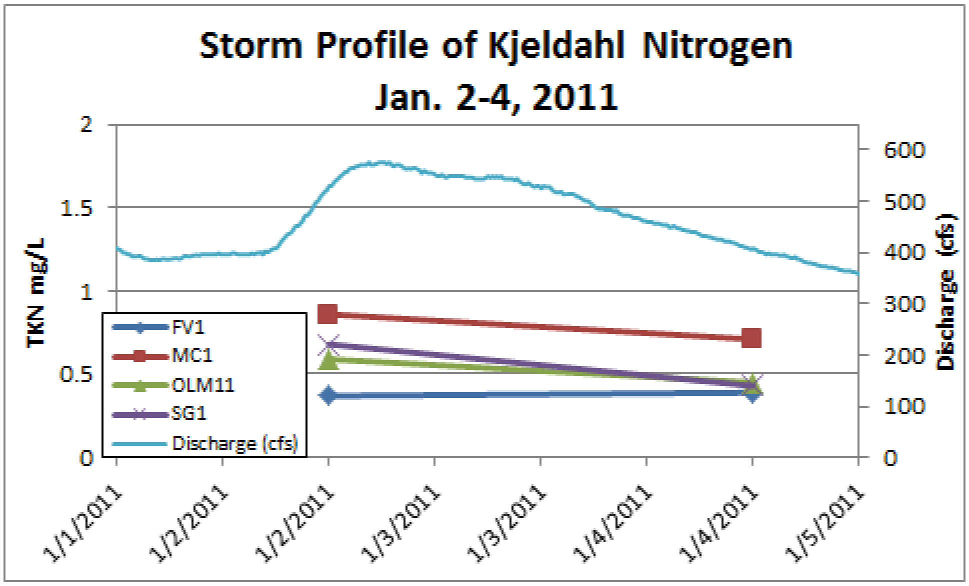
The fourth storm that was targeted for profile sampling was a storm of a quarter inch on January 3rd, 2011. Samples were collected on day one (1/3/11) and day three (1/5). This relatively small storm followed a major event on Dec. 28-29th of over three inches of rain and the start of the sampled storm which brought over ½ inches on New Year's Day. It would be expected many subdrainages would have been flushed out by the preceding major event and levels of pollutant concentrations would be near winter base flow levels.

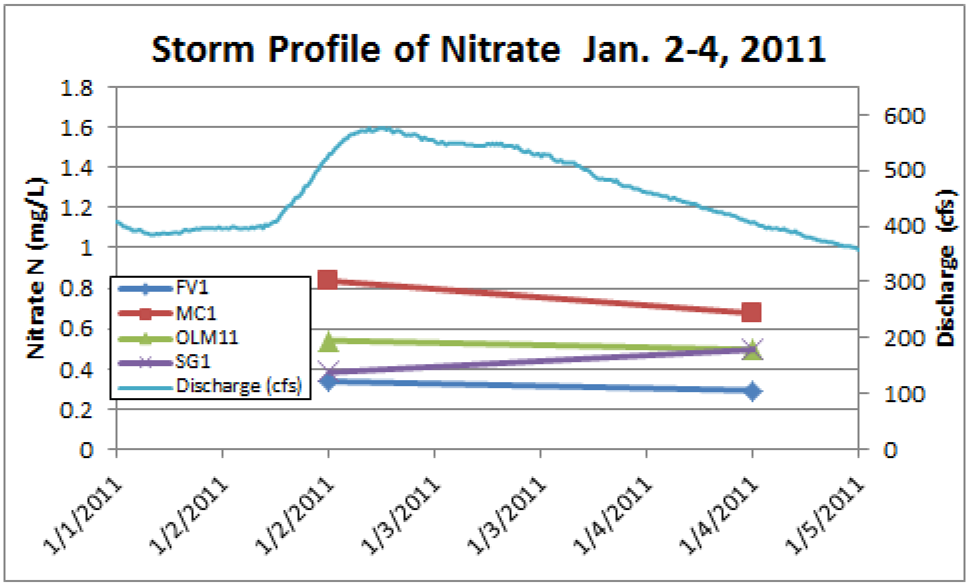
Below is a graph of hydrologic conditions during the storm period including the stream discharge from the streamgage on lower Lagunitas Creek near Point Reyes Station (USGS gage 11460600), the daily rainfall totals (from the RAWS weather station OVYC1 in the Olema Valley) and the creek site water quality sampling events.




Storm Profile of *E. coli* Jan. 2-4, 2011
E. coli MPN/100mL
1400
1200
1000
800
600
400
200
0
Discharge (cfs)
600
500
400
300
200
100
0
FV1
MC1
OLM11
SG1
Discharge (cfs)
1/1/2011
1/2/2011
1/2/2011
1/3/2011
1/3/2011
1/4/2011
1/4/2011


Storm Profile of Turbidity Jan 2-4, 2011
Turbidity NTU
40
35
30
25
20
15
10
5
0
Discharge (cfs)
600
500
400
300
200
100
0
FV1
MC1
OLM11
SG1
Discharge (cfs)
1/1/2011
1/2/2011
1/2/2011
1/3/2011
1/3/2011
1/4/2011
1/4/2011
1/5/2011

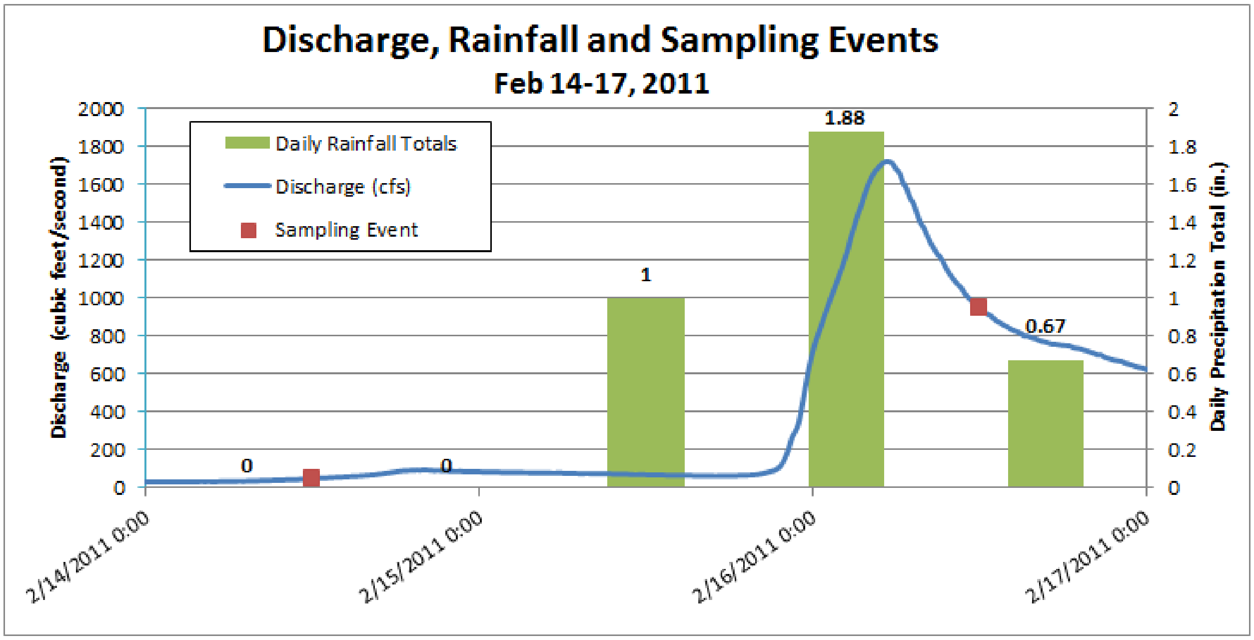


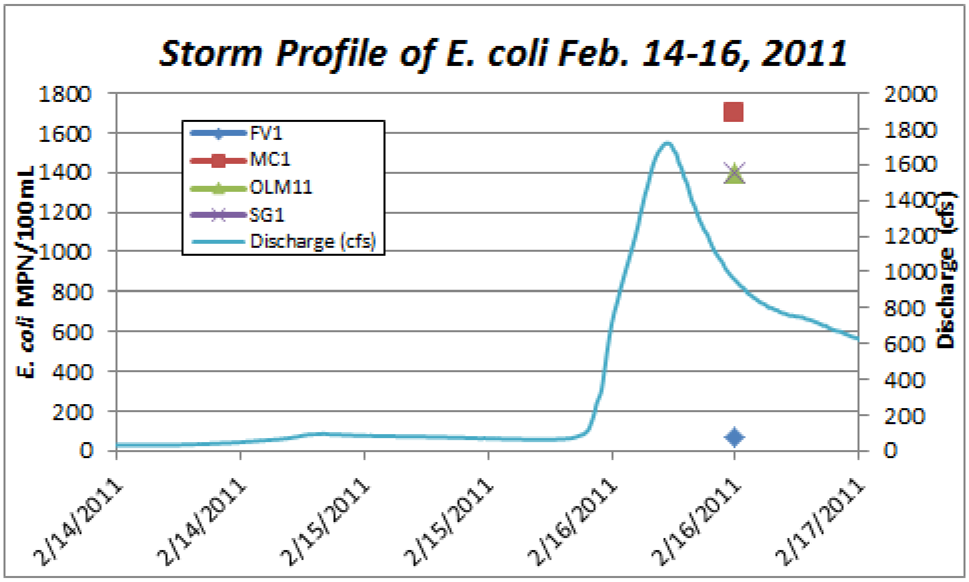


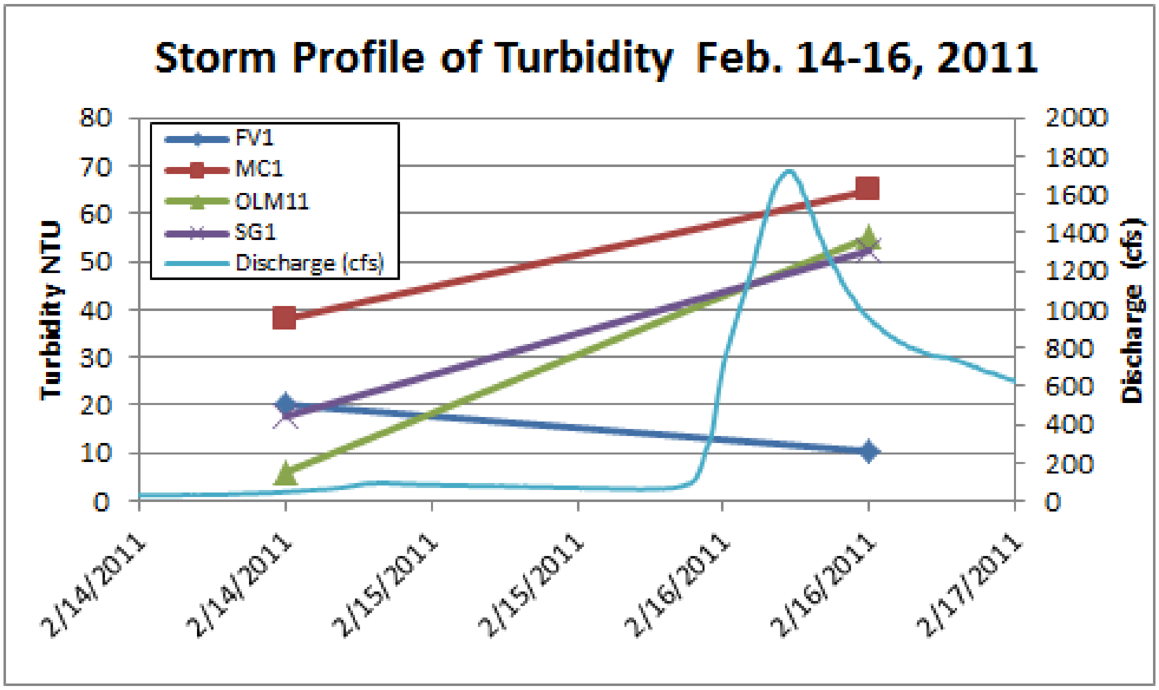
February 14-17th, 2011 Storm Profile

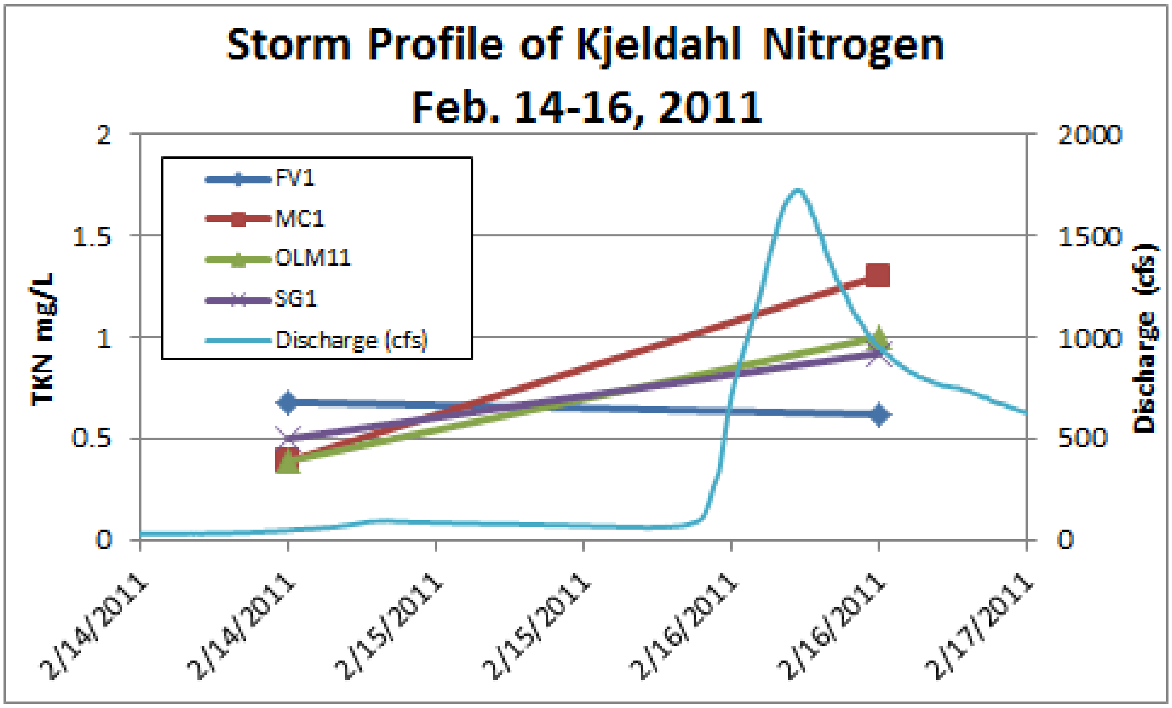
The fifth storm that was targeted for profile sampling was a storm of several inches over two days from February 15-17th, 2011. Samples were collected on day one (2/14/11) and day three (2/16). This storm continued, or was followed closely by another system that brought nearly two more inches of rain on Feb. 17-19th. The arrival of additional rains interrupted the storm profile.

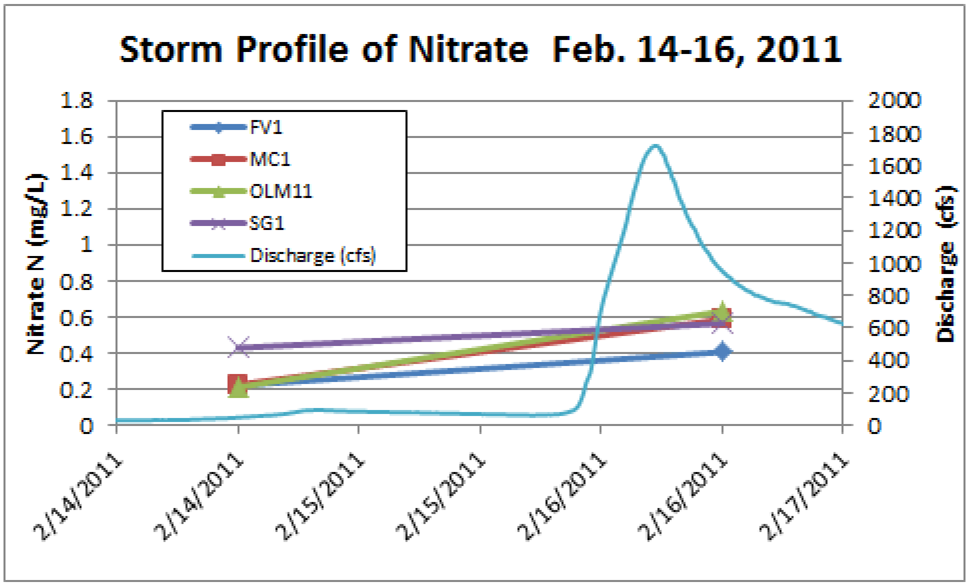
Below is a graph of hydrologic conditions during the storm period including the stream discharge from the streamgage on lower Lagunitas Creek near Point Reyes Station (USGS gage 11460600), the daily rainfall totals (from the RAWS weather station OVYC1 in the Olema Valley) and the creek site water quality sampling events.


Discharge, Rainfall and Sampling Events
Feb 14-17, 2011
Daily Rainfall Totals
Discharge (cfs)
Sampling Event
Discharge (cubic feet/second)
Daily Precipitation Total (in.)
2000
1800
1600
1400
1200
1000
800
600
400
200
0
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1.88
1
0.67
0
0
2/14/2011 0:00
2/15/2011 0:00
2/16/2011 0:00
2/17/2011 0:00


Storm Profile of E. coli Feb. 14-16, 2011
FV1
MC1
OLM11
SG1
Discharge (cfs)
E. coli MPN/100mL
Discharge (cfs)
1800
1600
1400
1200
1000
800
600
400
200
0
2000
1800
1600
1400
1200
1000
800
600
400
200
0
2/14/2011
2/14/2011
2/15/2011
2/15/2011
2/16/2011
2/16/2011
2/17/2011


Storm Profile of Turbidity Feb. 14-16, 2011
Turbidity NTU
Discharge (cfs)
0
10
20
30
40
50
60
70
80
0
200
400
600
800
1000
1200
1400
1600
1800
2000
FV1
MC1
OLM11
SG1
Discharge (cfs)
2/14/2011
2/14/2011
2/15/2011
2/15/2011
2/16/2011
2/16/2011
2/17/2011

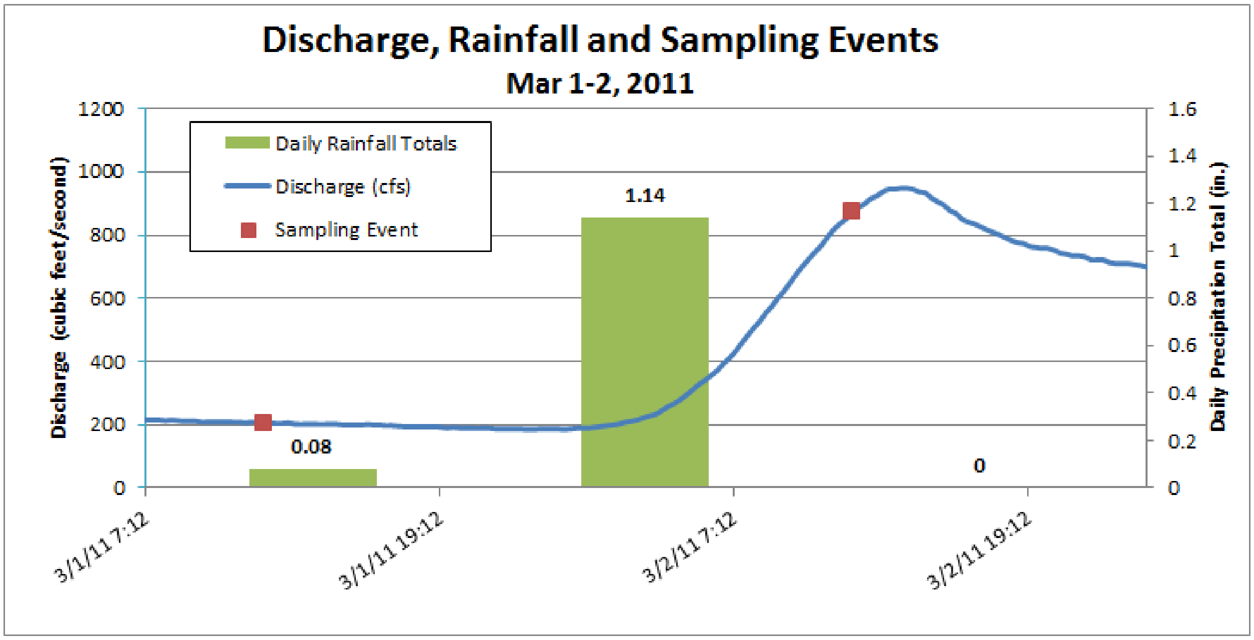

Storm Profile of Kjeldahl Nitrogen Feb. 14-16, 2011
TKN mg/L
Discharge (cfs)
0
0.5
1
1.5
2
0
500
1000
1500
2000
FV1
MC1
OLM11
SG1
Discharge (cfs)
2/14/2011
2/14/2011
2/15/2011
2/15/2011
2/16/2011
2/16/2011
2/17/2011

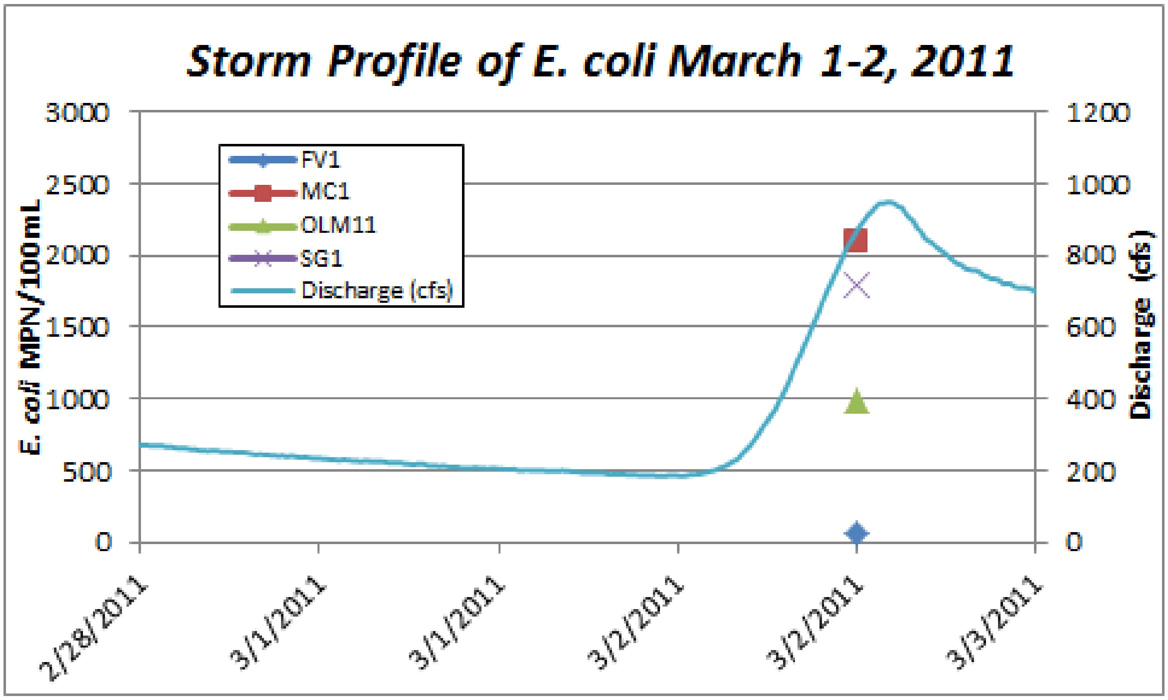


March 1-2, 2011 Storm Profile

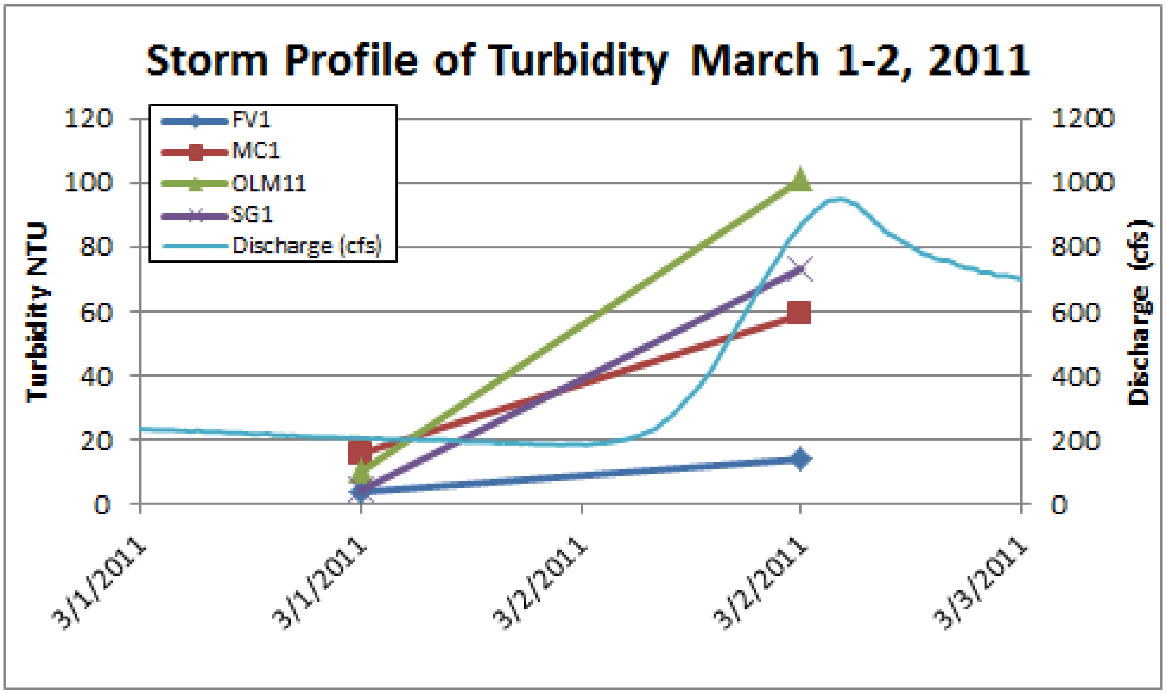
The sixth storm that was targeted for profile sampling was a storm of just over 1 ¼ inches over two days from March 1st-2nd, 2011. Samples were collected on March 1st as part of regular Trends Program sampling, because the bulk of the rain (1.18”) on the day, it was decided to collect a storm sample from the four Trends sites on day 2 (3/2). There was no falling limb sampling conducted during this storm due to laboratory and staff logistical conflicts.

Below is a graph of hydrologic conditions during the storm period including the stream discharge from the streamgage on lower Lagunitas Creek near Point Reyes Station (USGS gage 11460600), the daily rainfall totals (from the RAWS weather station OVYC1 in the Olema Valley) and the creek site water quality sampling events.

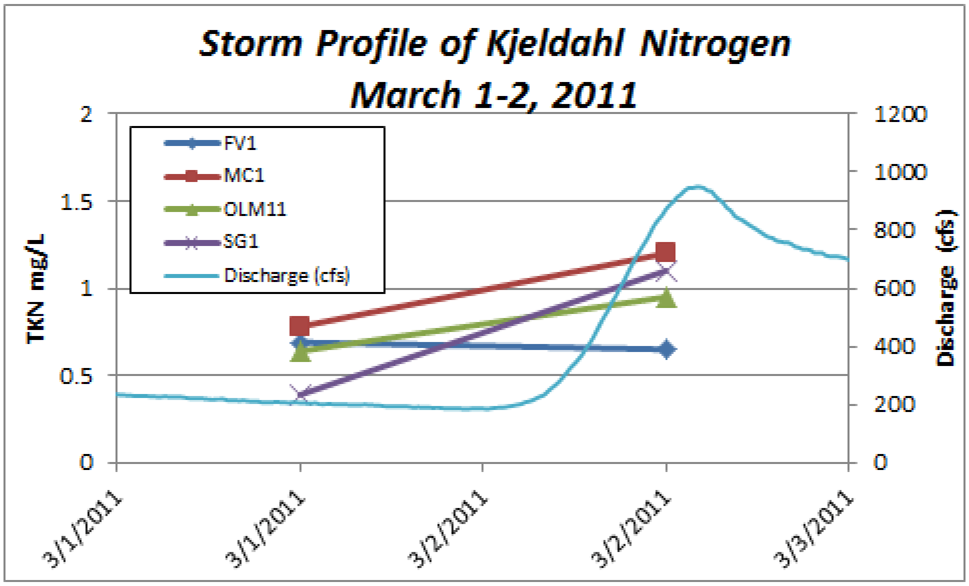


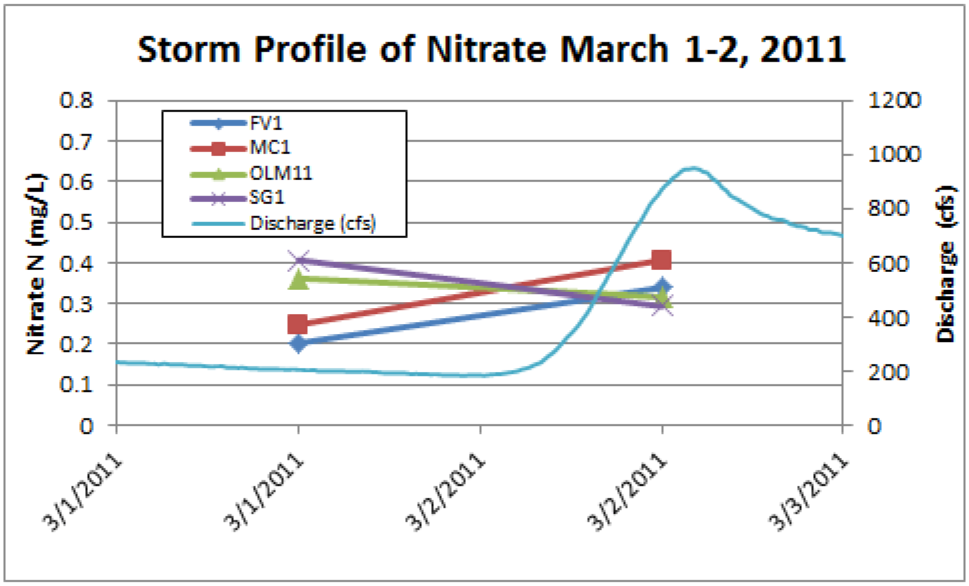


Storm Profile of E. coli March 1-2, 2011
E. coli MPN/100mL
Discharge (cfs)
FV1
MC1
OLM11
SG1
Discharge (cfs)
3000
2500
2000
1500
1000
500
0
1200
1000
800
600
400
200
0
2/28/2011
3/1/2011
3/1/2011
3/2/2011
3/2/2011
3/3/2011



Storm Profile of Turbidity March 1-2, 2011
Turbidity NTU
Discharge (cfs)
FV1
MC1
OLM11
SG1
Discharge (cfs)
120
100
80
60
40
20
0
1200
1000
800
600
400
200
0
3/1/2011
3/1/2011
3/2/2011
3/2/2011
3/3/2011

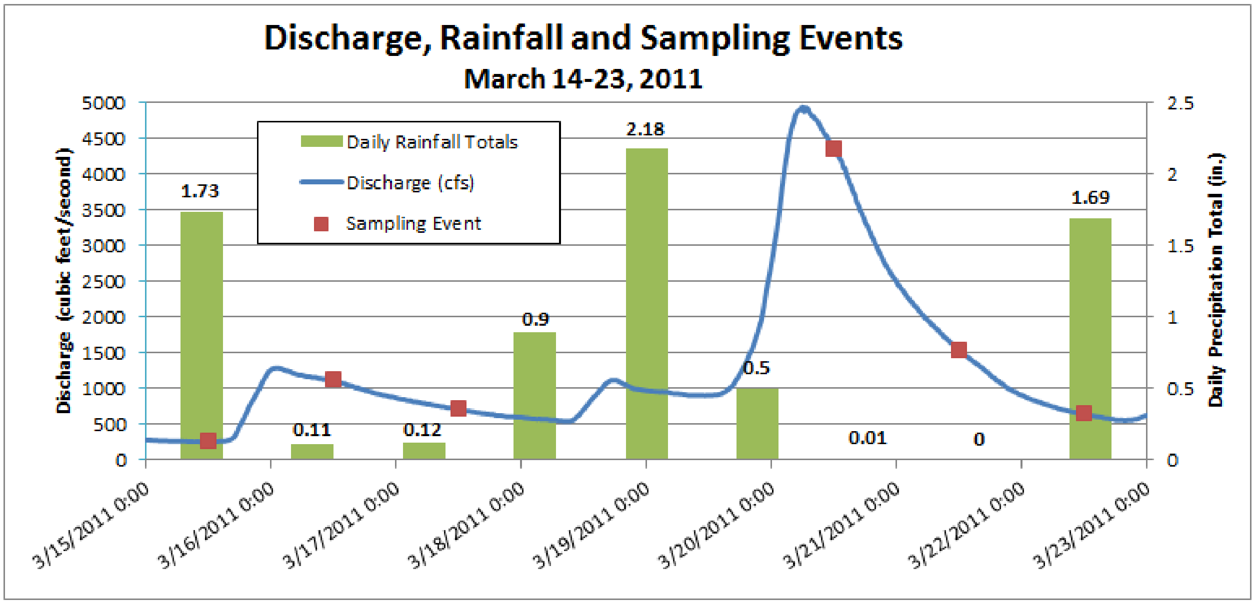


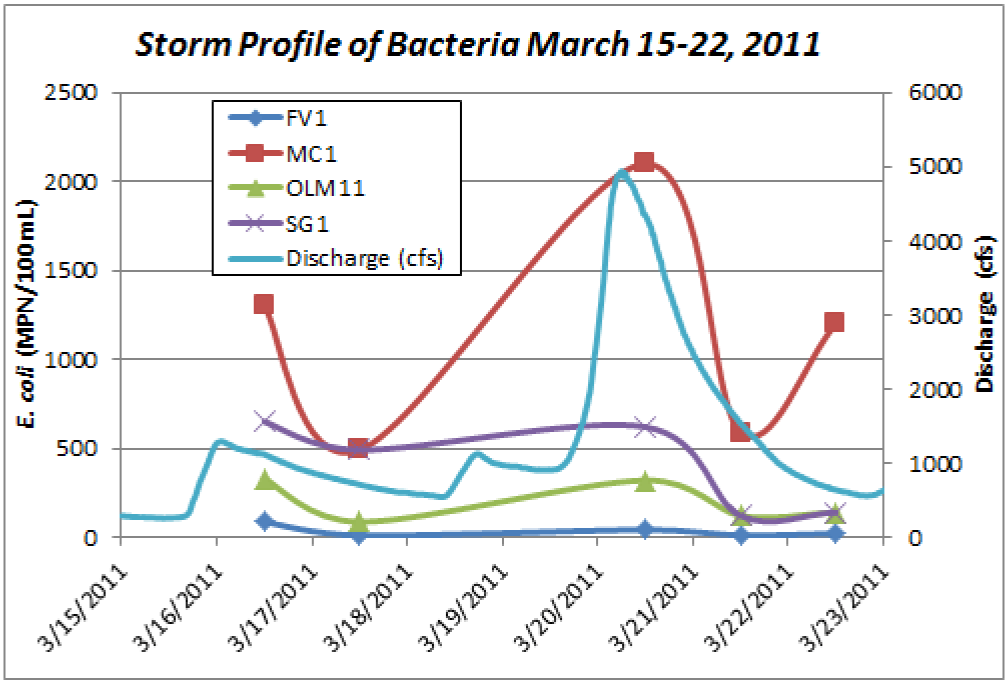


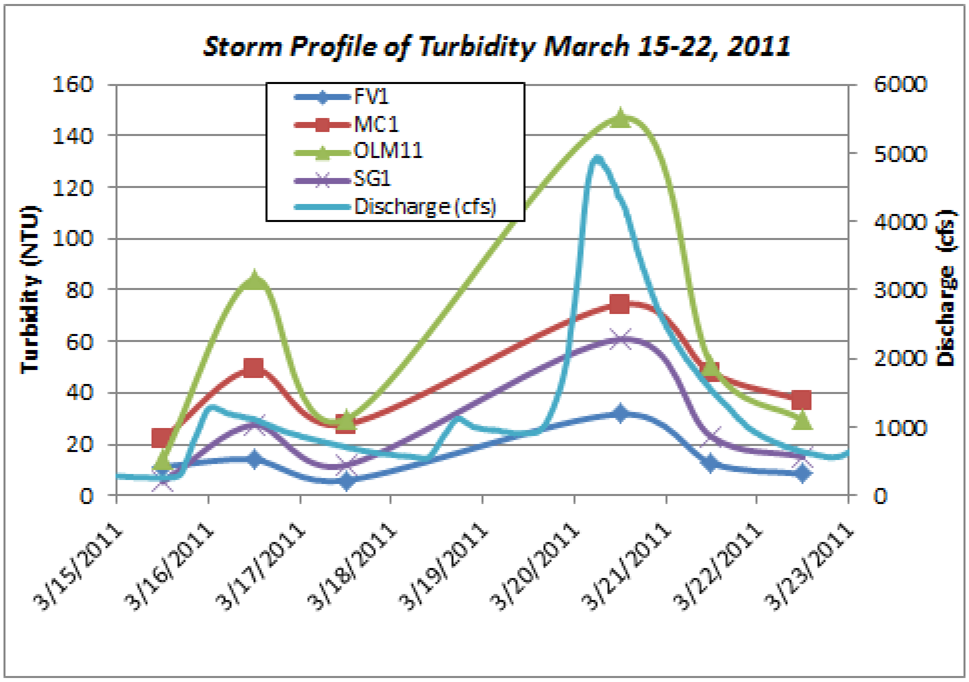
March 14-23, 2011 Storm Profile

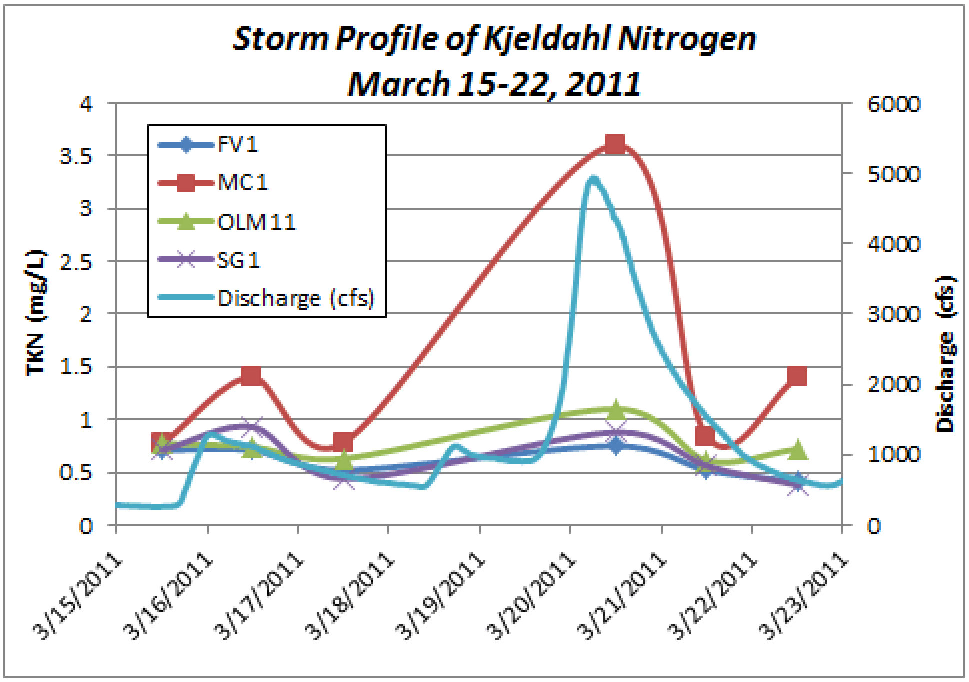
The seventh and eighth storms that were targeted for profile sampling occurred during the third week of March. The first sampling was conducted on March 15th during a storm of nearly 1.75" of precipitation. Samples were collected during light rain (~0.10"/day) on March 16th-17th during the falling limb of the hydrograph. Rains resumed over the weekend with the accumulation of over 2 ¼"of precipitation on March 18th and 19th. Because of the sustained storm conditions, sampling was resumed on March 20th just after the peak of the storm, samples were collected on the following two days (3/21 and 3/22) during the falling limb of the hydrograph. Another major rain event arrived on 3/23, interrupting the storm profile.

Below is a graph of hydrologic conditions during the storm period including the stream discharge from the streamgage on lower Lagunitas Creek near Point Reyes Station (USGS gage 11460600), the daily rainfall totals (from the RAWS weather station OVYC1 in the Olema Valley) and the creek site water quality sampling events.

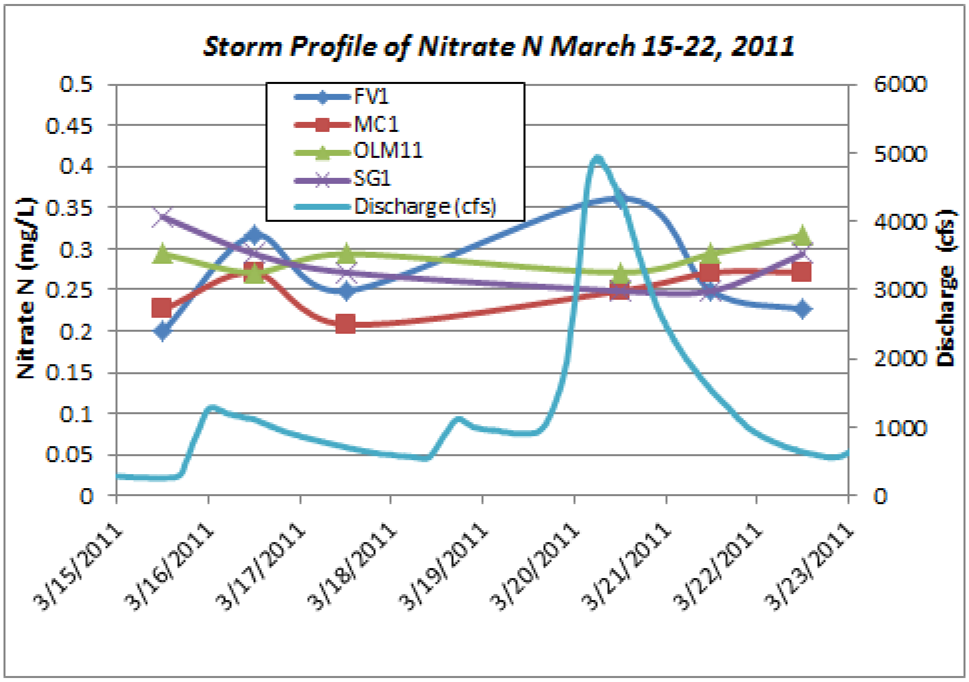








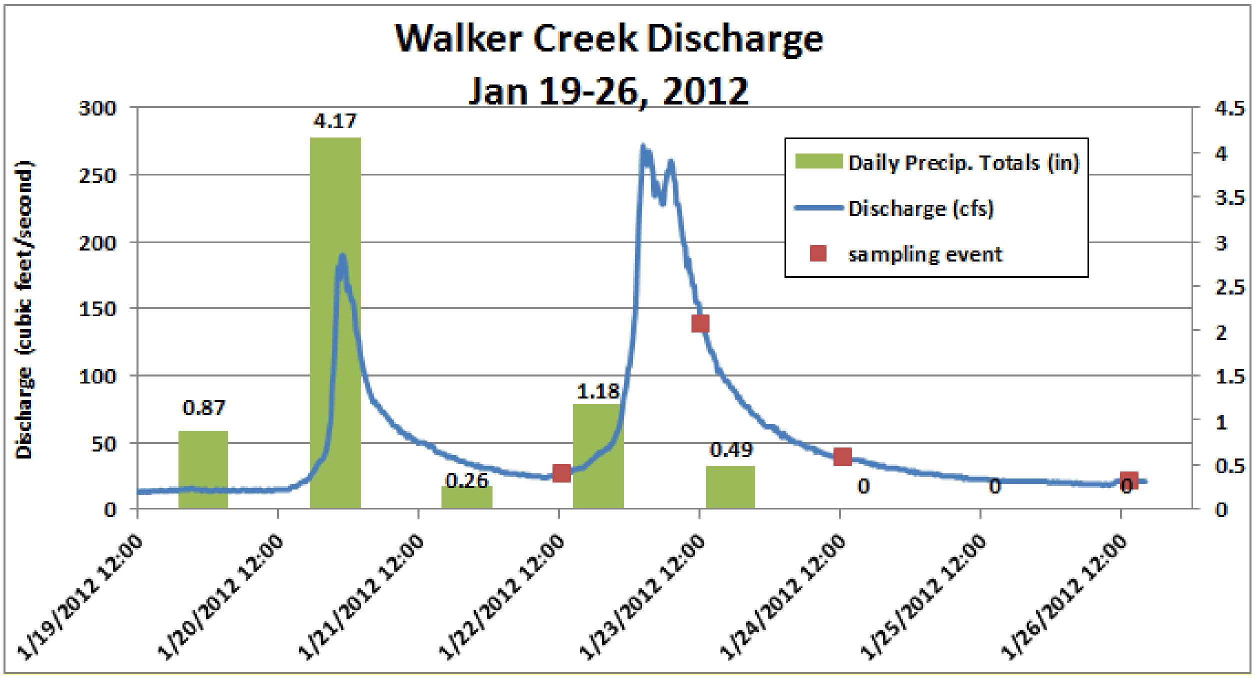
The TKN graph above demonstrates the episodic nature of loading from some watersheds. Of note is the sample from Millerton Gulch from near the peak flow on 3/20. The TKN concentrations at Millerton Gulch were about 3.5-times those from the other three Trends Program sites. Of note, also, was a similar result and similar comparative levels measured in the bacteria samples from the four sites. This result suggests the connection of an upstream source of bacteria, and organic nitrogen or ammonia in Millerton Gulch after several inches of sustained rain in two days.

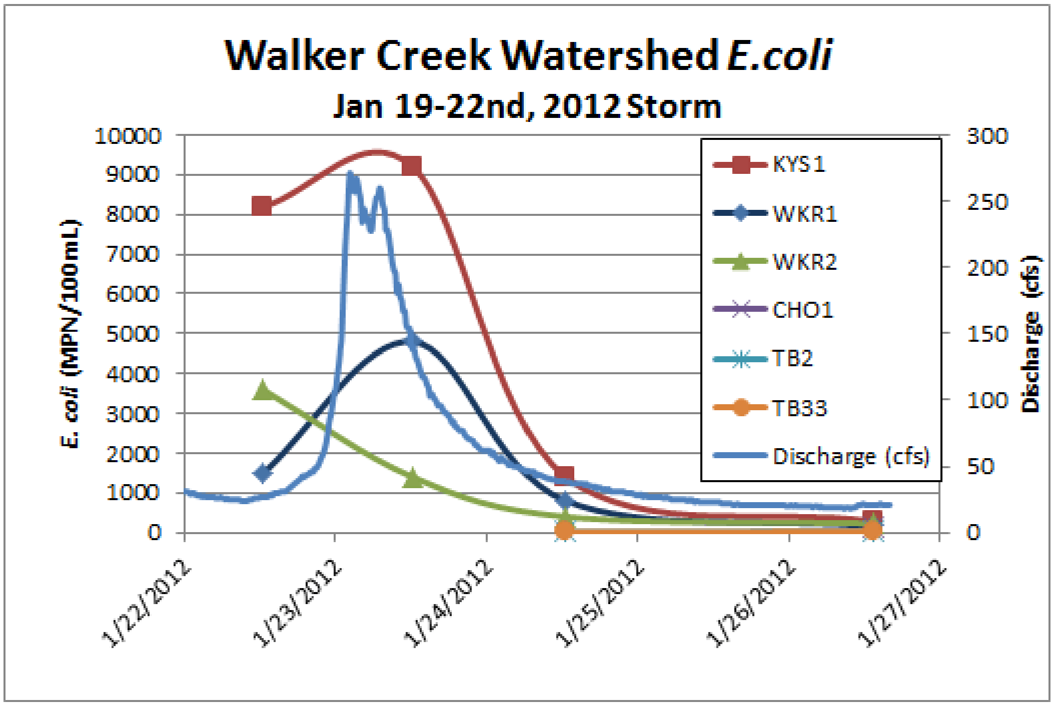


January 22-26, 2012 Storm Profile

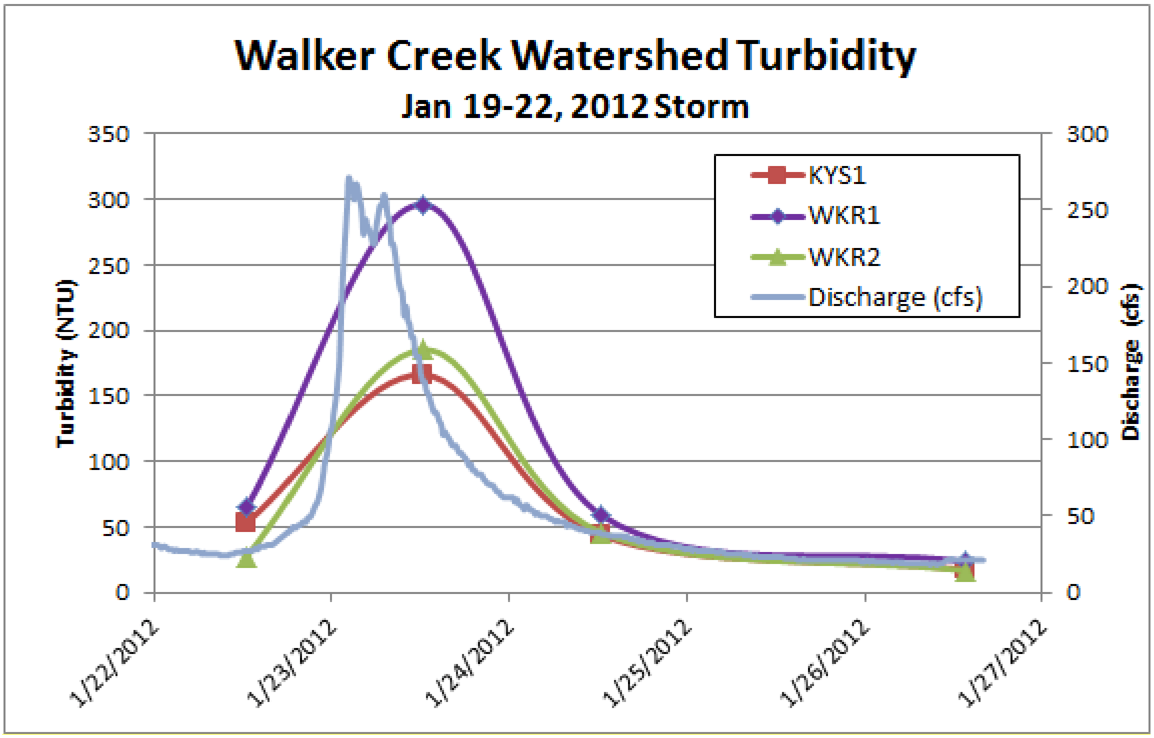
The final storm that was targeted for the Source Area Program profile sampling was a storm of just over 1 ½ inches over two days from January 22nd -23rd , 2012. Samples were collected from sites in Walker Creek and in the mouth of Walker Creek in the Bay on the 22nd, 23rd, 24th and 26th. The sampled storm followed a major event of over 5 ¼-inches that occurred on January 19-21.

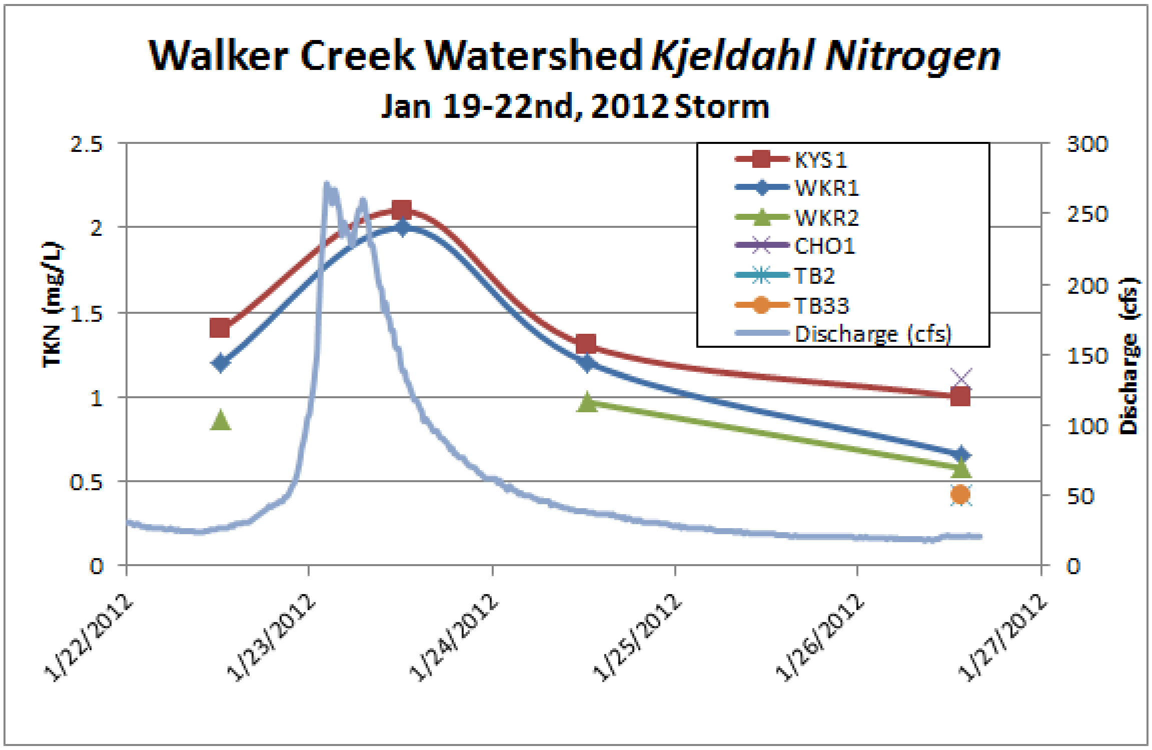
Below is a graph of hydrologic conditions during the storm period including the stream discharge from the streamgage Walker Creek at Walker Creek Ranch (USGS gage 11460750), the daily rainfall totals (from the RAWS weather station OVYC1 in the Olema Valley) and the creek site water quality sampling events.

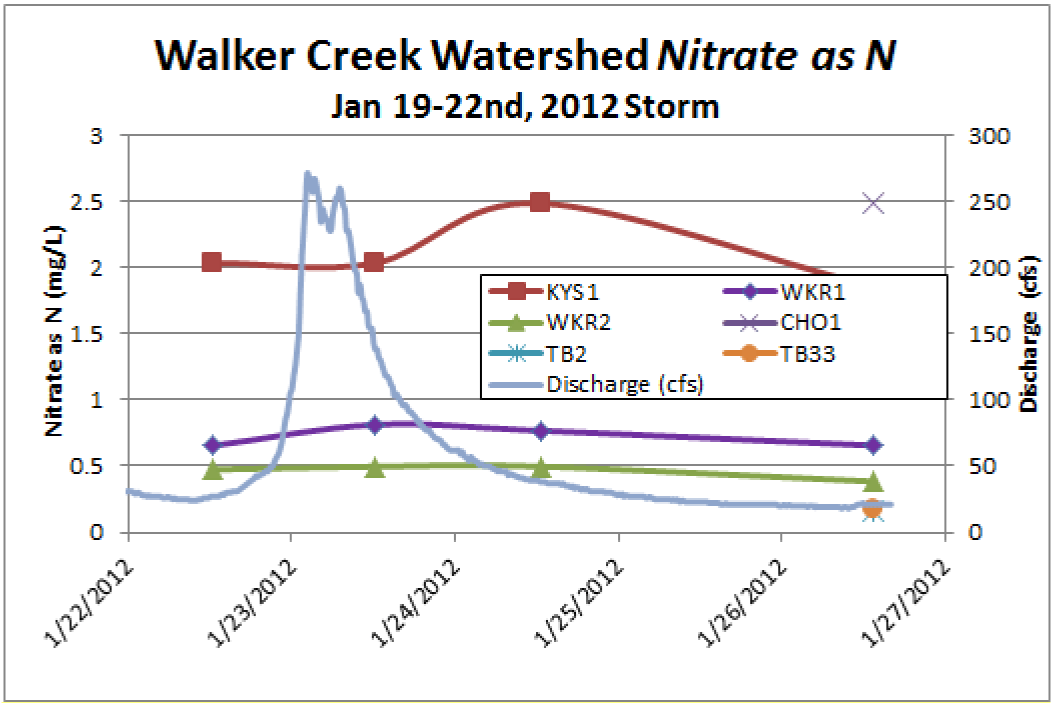




The results of *E. coli* testing from sites in Walker Creek and in the delta in the Bay show that Keys Creek had bacteria levels near peak flow between two and nine-times higher than those from other watershed sites. These results are consistent with the long-term Trends Program monitoring from Keys Creek compared to the other watershed sites.


Walker Creek Watershed Turbidity
Jan 19-22, 2012 Storm
Turbidity (NTU)
Discharge (cfs)
KYS1
WKR1
WKR2
Discharge (cfs)
0
50
100
150
200
250
300
350
0
50
100
150
200
250
300
1/22/2012
1/23/2012
1/24/2012
1/25/2012
1/26/2012
1/27/2012


Walker Creek Watershed *Kjeldahl Nitrogen*
Jan 19-22nd, 2012 Storm
TKN (mg/L)
Discharge (cfs)
KYS1
WKR1
WKR2
CHO1
TB2
TB33
Discharge (cfs)
0
0.5
1
1.5
2
2.5
0
50
100
150
200
250
300
1/22/2012
1/23/2012
1/24/2012
1/25/2012
1/26/2012
1/27/2012



The result of nitrate analysis shows that Keys Creek has concentrations almost twice as high as other creek sites in the Walker Creek watershed. This is despite the significant flushing that would have occurred in the large storm event that immediately preceded this sampling. These results are consistent with the Trends Program monitoring results that have shown sustained elevated levels of nutrients from the Keys Creek watershed.

Conclusions

The storm profiles resulting from the Source Area Program storm profile monitoring at Trends Program sites has provided valuable evidence of pollutant loading patterns between sites between and within major subwatersheds. The storm profiles reinforce some evidence from the larger Trends Program where persistently elevated pollutant concentrations from San Geronimo Creek and Keys Creek were observed relative to other monitored sites. The additional storm sampling at Trends Program sites provided additional data points for pollutant concentration under extreme conditions in the targeted watersheds.

In the future, this data can be analyzed for correlations between rainfall accumulation or intensity and pollutant concentrations observed in the each of the monitored subwatersheds, and can be combined with Trends Program data to compare water quality under storm vs. non-storm conditions. Studies can be repeated in the future to gauge the success of water quality improvement efforts, whether restoration or implementation of Best Management Practices over time.